JOURNAL OF AGRICULTURAL RESEARCH

VOL. XXX WASHINGTON, D. C., APRIL 1, 1925 No. 7

RELATION OF WEATHER CONDITIONS TO THE SPREAD OF WHITE PINE BLISTER RUST IN THE PACIFIC NORTHWEST[1]

By L. H. PENNINGTON [2]

Collaborator, Office of Investigations in Forest Pathology, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

Weather conditions to a large extent determine the spread and severity of fungous diseases of plants. White pine blister rust is no exception to the rule. The direction and rapidity of spore distribution over long distances depend upon winds. Favorable moisture and temperature conditions are necessary for germination of the spores and consequent infection of the host plants.

Moisture conditions are more variable than temperature and seem to determine the amount of infection which may occur. If moisture conditions are favorable, temperature conditions also are practically certain to be favorable. Particular attention has, therefore, been given to the correlation between the spread of the rust and the winds and moisture conditions.

The western white pine, *Pinus monticola* Dougl., is practically the only pine to be taken into consideration. There are several species of Ribes in the region under discussion. (See fig. 1.) Some qualifications will be necessary because of differences in both abundance and susceptibility to infection of Ribes in different localities.

It has not been possible to follow the course of the disease from year to year in the Northwest. It has, therefore, been necessary to determine, as nearly as possible, by field studies during the seasons of 1922 and 1923 the year of infection as well as the amount and direction of spread of the rust. This has been done, and it is now possible to determine in a general way how often heavy infections may be expected to occur in places containing both pines and Ribes. It is possible also to make some estimate of the length of time which will be required for the disease to spread by natural means into regions now free from it.

DETERMINATION OF SEASON OF INFECTION

Special efforts have been made to determine the year of infection in all places in which the rust has been studied. In young and vigorous trees it is practically always possible to determine the internode in which infection began. Until recently infections were classified according to the year's internode in which they first appeared. This method was found to be inaccurate. Earlier tabulations in which no reference to the age of the canker was given are not good indicators as the to year of infection.

During the season of 1922 a large number of incipient infections were found in the internodes of 1917, 1918, 1919, and 1920. Table I shows the distribution of 176 of these infections upon a few pines near Bold Point, British Columbia. (For location of infection centers see fig. 2.) There were many Ribes near these pines.

[1] Received for publication June 11, 1924; issued June, 1925.

[2] The writer wishes to express his gratitude to J. S. Boyce, forest pathologist for Washington and Oregon, and to G. B. Posey and S. N. Wyckoff, pathologists in charge of blister-rust control in 1922 and 1923, respectively, for the Western States. Each has been most cordial in his cooperation and has aided in the collection of data in every possible way. Particular credit is due to Harry G. Lachmund, junior pathologist, who most ably and faithfully assisted during the summers of 1922 and 1923 in the collection and preparation of field data. The writer acknowledges the cordial cooperation of the meteorologists and other Government and State officials in the Western States and British Columbia. He is especially indebted to the following: A. T. Davidson, in charge of blister-rust scouting for the Dominion Government, who has furnished valuable data secured by himself and his scouts and who has aided materially in other ways; and F. Napier Denison, superintendent, Gonzales Heights Observatory, Victoria, British Columbia, who furnished all the available meterorological data for British Columbia.

The large majority of the infected internodes produced aecia in 1923 for the first time. As nearly as could be determined, not over 10 or 12 of them failed to produce aecia in April or May, 1923. Upon some of the branches there were so many infections that they coalesced before aecia were produced. On the other hand, some of the 10 or 12 which did not produce aecia may have been 1921 infections, which were beginning to appear in 1923.

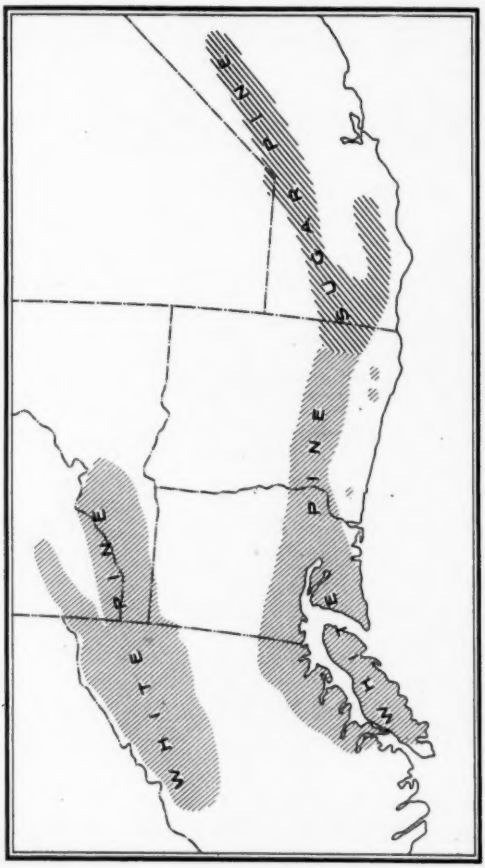

FIG. 1.—Map showing distribution of western white pine (*Pinus monticola*) and sugar pine (*P. lambertiana*) in the western United States and Canada

TABLE I.—*Distribution of 176 infections found in 1922 on pines near Bold Point, B. C.*

Internode of [a]—	Number of infections
1917	5
1918	36
1919	113
1920	22

[a] By "internode of 1917" is meant that part of a stem or branch which began its growth in the growing season of 1917.

It would appear that all or nearly all of these infections occurred in the same year, since they developed practically simultaneously and produced aecia first in 1923. It is very evident that no infections which began in the 1920 internodes could have resulted from exposure earlier than 1920. If those in the internodes of 1917, 1918, or 1919 had occurred earlier than those in the 1920 internodes, they would have been older than the infections in the 1920 internodes and the greater part of them would have produced

FIG. 2.—Location of infection centers: ●, Pine infection; ▲, 1922 Ribes infection; ■, 1923 Ribes infection

aecia in 1920, 1921, or 1922. On the other hand, if the infections had occurred in 1921, there should have been some fruiting cankers in the 1921 internodes. Several thousand infected branches and stems were examined in 1923. In only one instance was a fruiting canker found in a 1921 internode. It is believed that aecia are usually produced in the third year after infection occurs (*8, p. 25–26*).[3] This is borne out by the writer's field studies both in New York and in the Northwest.

From Table I it is evident that considerable infection occurred in 1920 near Bold Point, British Columbia. Similar observations were made in other localities in the immediate vicinity of older pine infections and Ribes. As field observations were continued through the summer of 1923, it became increasingly apparent that there had been a great deal more infection in 1921 than in 1920. The data given in Table II are typical for conditions found early in July with respect to incipient infections and those which produced aecia in 1923 for the first time.

TABLE II.—*Distribution of 141 infections found early in July, 1923*

Internode of—	Number of infections
1918	13
1919	45
1920	72
1921	11

Nineteen of these produced aecia in 1923 and were probably all infections of 1920. They were distributed as shown in Table III.

TABLE III.—*Distribution of 19 infections, probably of 1920, producing aecia for the first time in 1923*

Internode of—	Number of infections
1918	6
1919	11
1920	2

The 19 infections shown in Table III subtracted from the 141 in Table II leave 122, distributed as shown in Table IV. These are all, or nearly all, infections of 1921.

TABLE IV.—*Distribution of 122 infections found in July, 1923, all, or nearly all, of which are infections of 1921*

Internode of—	Number of infections
1918	7
1919	34
1920	70
1921	11

The totals 19 and 122 (Tables III and IV) show fairly well the relative number of 1920 and 1921 infections apparent by the first week in July. As the season advanced both the actual and the relative number of incipient (1921) infections increased. Table V shows the distribution of 162 incipient infections counted the second week in August.

TABLE V.—*Distribution of 162 incipient infections found during second week of August, 1923*

Internode of—	Number of infections
1918	2
1919	32
1920	97
1921	31

These tables indicate that in any one year infection may occur in the internodes of four successive years.

The western white pine commonly retains its needles four years; that is, during the summer of a given year, as 1921, there will be needles upon the internodes of 1918, 1919, 1920, and 1921. In a favorable season it is probable that infection may occur in any of these needles. Practically all the rust mycelium, however, which might develop in the oldest needles would fail to reach the bark, since those needles would die and fall by the end of that season.

Since in any one year infection may occur in the internodes of three and occasionally four years, it is obviously impossible to determine by the position of a single canker the exact year in which infection occurred. When, however, a large number of cankers of approximately the same stages of development are found distributed through the internodes of three or four succes-

[3] Reference is made by number (italic) to "Literature cited," p. 608.

sive years, it is practically certain that infection resulted from exposure to sporidia in the last of these years.

A great many of the cankers found in 1922 had evidently produced aecia for three years, apparently beginning in 1920. This would indicate infection in 1917. Tabulations made in 1922 included all the infections found in any one place regardless of their stage of development. Table VI shows the distribution of 110 cankers found July 18, 1922, in one limited area near Mile 72, Pacific Great Eastern Railway, British Columbia.

TABLE VI.—*Distribution of 110 cankers found July 18, 1922, near Mile 72, Pacific Great Eastern Railway, British Columbia*

Internode of—	Number of infections
1914	1
1915	8
1916	59
1917	42

The data in this table are fairly typical for the distribution of the older cankers which were found in many places. Infection in 1917 is indicated.

Table VII shows the distribution of 54 cankers as found by A. T. Davidson (*1*) May, 1922, in a swamp at North Vancouver, British Columbia.

TABLE VII.—*Distribution of 54 cankers found May, 1922, in a swamp at North Vancouver, B. C.*

Internode of—	Number of infections
1912 or 1913	5
1915	8
1916	29
1917	12

With the exception of the five in the internodes of 1912 or 1913, these cankers were apparently of the same stage of development. They were probably the result of infection in 1917. The five in the internodes of 1912 or 1913 were several years older than the others. Some of them had started in branches which were dead when found in 1922. It was impossible to determine within two or three years the internode in which infection first occurred. A reexamination of one of the old cankers showed that it might have had its origin in the internode of either 1910 or 1911.

A few of the oldest cankers were found in other places. Two at Daisy Lake and one at Mile 28, Pacific Great Eastern Railway, evidently started in the internodes of 1912 or 1913. One at Thurston Bay, British Columbia, appeared to have started in the 1912 internode; one on Green Mountain, a mile from Bold Point, might have started in either the 1910 or the 1911 internode.

These oldest cankers were not less than 3 nor more than 5 years older than the cankers which seemed to have resulted from infection in 1917. All of them had their origin in the internodes of the years 1910 to 1913, inclusive. Although it is not certain that all began in 1913, any or all of them, from their apparent stage of development and position, might have resulted from infection in 1913. Tabulations of cankers in the immediate vicinity of these oldest cankers do not indicate infection in 1914 or 1915. They do indicate, however, that there was a little infection in 1916, much in 1917, a little in 1918 and 1919, much in 1920, and a great deal in 1921. If the oldest cankers had resulted from infection before 1913, there should have been enough aeciospore production to have caused at least a little infection of Ribes and pine in the immediate vicinity earlier than 1916.

The data presented might seem to indicate that pine infection in any given locality has been largely proportional to the number of aeciospores produced in that locality. This is undoubtedly true in limited areas where an abundance of Ribes is present. It is also true that the greater the amount of aeciospore production the greater the chances for their wide distribution and infection of Ribes. The more important fact, however, is that initial infection of pine in localities where the disease has not previously occurred, and heavy infection near Ribes as well as at some distance from them, have not been proportional to aeciospore production. From the data obtained it is evident that the rust became established in several localities, probably in 1913. No evidence was found to indicate that it was established in any other locality before 1917. There is no reason to believe that there were less aeciospores in 1914, 1915, or 1916 than there were before 1914. As a matter of fact, there were probably many more in 1916 than in any previous year.

In 1917 very heavy infection occurred, not only near the older infections, but at considerable distances from Ribes. At the same time the rust became established in many localities where it had not been present previously.[4] In 1918 and 1919 aeciospore production was probably greater than in any previous year, yet infection was apparently less than in 1917, and the rust became established in few if any places where it was not already present. In 1920 the production of aeciospores was enormously increased, for the infections of 1917 resulted in aecia in 1920. No new centers of infection seem to have been established and heavy infection was confined to the immediate vicinity of fruiting cankers near Ribes.

The field studies of 1923 showed the relatively greater amount of infection in 1921 than in 1920. (See Tables II, IV, and V.) Incipient, or 1921, infections were found in the Fraser Valley near Abbotsford, B. C., and in various places along the Pacific Great Eastern Railway, not only in localities in which no 1920 infections were found, but at much greater distances from the infecting Ribes than any of the 1920 infections. They were found frequently as much as a mile from the infecting Ribes. The 1920 infections, on the other hand, were seldom over 100 yards from the infecting Ribes. The infection of pine in the North Vancouver swamp illustrates very well the frequency of general or widespread infection. In Table VII it is shown that in the North Vancouver swamp there was infection probably in 1913 and again in 1917. Further studies made in August 1923 by H. G. Lachmund [5] showed incipient infections such as those noted in Table V. These indicate a third period of infection in 1921.

From the tabulation given and from numerous field observations, the years of heaviest and most widespread infection appear to have been 1913, 1917, and 1921. As these waves or periods of infection can not be explained on the basis of abundance of aeciospore production, the attempt was made to correlate them with weather conditions.

HISTORY AND DISTRIBUTION OF THE RUST

It has already been shown that considerable infection of pine had occurred in British Columbia not later than 1913. Infection occurred at North Vancouver, at various places along the route of the Pacific Great Eastern Railway, at least 60 miles north of Vancouver, and at Bold Point, Thurston Bay, and Shoal Bay, a distance of 125 miles northwest of Vancouver.[6] There must have been considerable aeciospore production to have caused infection in so many widely separated places.

The only place in which the rust is known to have been present in the Province at that time is Point Grey, near Vancouver. In May, 1922, Davidson (*1*) found on Point Grey, near Vancouver, 180 eastern white pines (*Pinus strobus*), of which 68 were infected with the rust. Some of these had cankers in the growth of 1910. The 180 trees were all that remained of 1,000 which had been imported in 1910 from Ussy, France. Since infected white pines are known to have been shipped from Ussy in 1910 (*7, p. 36*), it is altogether probable that some of the trees imported into Vancouver were already infected. If so, aeciospores should have been produced by 1913, and it is of course entirely possible that they were produced in 1910, 1911, and 1912 also. The plantation on which the infected trees were growing was in an exposed situation upon one of the highest points of Point Grey, where the escaping aeciospores could have been caught easily by the winds and carried in every direction.

It is known that some five-needle pines were imported into Victoria from Europe earlier than 1910. There is no evidence, however, to show that any of them were diseased, nor is there any reason to believe that any pines have been carried into or transplanted in the other places in British Columbia where early infection occurred. Nor is it likely that the rust was carried into the places outside of Vancouver on cultivated black currants, for although these plants are found fre-

[4] LACHMUND, H. G. STUDIES ON WHITE PINE BLISTER RUST IN THE PACIFIC NORTHWEST. Report for 1923. [Unpublished. Typewritten copy in Office of Blister Rust Control, Bureau Plant Industry, U. S. Dept. Agriculture.]

PENNINGTON, L. H. FIELD INVESTIGATIONS OF THE WHITE-PINE BLISTER RUST IN WASHINGTON AND BRITISH COLUMBIA. Report for 1922. [Unpublished. Typewritten copy in Office of Blister Rust Control, Bureau of Plant Industry, U. S. Dept. Agr.]

[5] LACHMUND, H. G. Op. cit.

[6] See map (fig. 2) for localities mentioned.

quently in British Columbia, most of the oldest infections noted above were in places where they were absent. None were found at Thurston Bay and there was no evidence that any had ever been planted in that locality. The oldest infections at Bold Point were in a mountain ravine fully a mile from any black currants. This does not mean that the black currants were not susceptible to the rust, but rather that there was an abundance of susceptible wild Ribes near the infected pines. As a matter of fact, these cultivated black currants apparently caused infection in pines near them in 1917 and again in 1920 and 1921. At Shoal Bay the single old infection and two of more recent date evidently came from old cultivated black currants.

It has been pointed out that there was little or no infection in British Columbia in 1914 or 1915 and very little in 1916. In 1917, however, there seems to have been a great deal and a much wider spread of the rust than in any previous year. It advanced to the east 60 miles as far as Agassiz, 40 miles southeast to Blaine, Wash., north and west 150 miles practically to the limits of the white pine in the coast belt, and apparently eastward for at least 150 miles across the dry belt to Canoe, Revelstoke, and Beaton.

The infections at Agassiz were upon the outer branches of 30-year-old *Pinus strobus*[7] near cultivated black currants. The infected pine near Blaine and in nearly all the other places in the Fraser Valley were found in the vicinity of cultivated black currants.

Fourteen infections were found in 1922 east of the dry belt, 7 at Canoe, 1 at Revelstoke, and 6 at Beaton. They were apparently of the same age and were in the 1916 and 1917 internodes (*1*). Of seven cankers examined by the writer, five were in the 1916 internode and two in 1917 internodes. They were apparently of the same age as those found in the 1915, 1916, and 1917 internodes in the coast region.

No infection was found south of Blaine, although much more intensive scouting was carried on in Washington than in British Columbia. A great deal of the scouting was done by men who worked both in Washington and in British Columbia.

In 1918 and 1919 there was a little infection in the vicinity of the oldest cankers in the coast region.[8] In 1920 there was considerable infection in the immediate vicinity of Ribes near 1917 infections (see Table I). In 1921 there was a much heavier infection than in 1920 (see Tables II, IV, and V).

Very careful search was made during the summer of 1923 in the interior of British Columbia, particularly at Canoe, Revelstoke, and Beaton, to find and destroy all pine infections. Of these 88 are shown in Table VIII.

TABLE VIII.—*Distribution of 88 pine infections found at Canoe, Revelstoke, and Beaton, B. C., during the summer of 1923*

Internode of—	Number of infections at—		
	Canoe	Revelstoke	Beaton
1917	4	5	1
1918	3	11	1
1919	1	9	9
1920	6	14	10
1921	6	8	----

In addition to the 88 infections mentioned in Table VIII, 10 were later reported by Davidson (*2*). These with the 14 found in 1922 and the 1 at Nakusp make a total of 113 for the four centers east of the dry belt. These apparently represented three stages in the development of the disease, incipient infections, cankers of one year, and those which had produced aecia for three or four years. This is a very small number upon which to determine the exact years of infection. It has been suggested that the original infection occurred in 1918. From the age of the cankers, however, and their distribution in the branches and stems it seems more probable that infection first occurred in three of the localities in 1917, and that later infection occurred in 1920 and 1921. The single infection found at Nakusp was in the internode of 1919 or 1920. This could not have occurred earlier than 1919, and since it produced aecia in 1923, it probably did not occur later than 1920.

[7] These trees were brought from Ontario in about 1894 or 1895. No evidence was found to indicate that any of them were infected before 1917.

[8] One infection at least occurred in either 1919 or 1920 at Nakusp, in the Columbia Valley.

There is no evidence that infection in these widely scattered centers was caused by the introduction of diseased pines or Ribes. No five-needled pines were found, except native *Pinus monticola*.

Since 1912, and particularly during the period of the war, there seems to have been very little transporting or planting of ornamental stock in British Columbia. The infections in pine were found in native trees in the immediate vicinity of old black currant bushes. The bushes at Revelstoke were said to have been brought from eastern Canada in 1898. It would have been a very unusual thing if the rust had been introduced into any one of these places upon pines or Ribes. That it should have been introduced into three or four widely separated places is practically outside the range of possibility. The Canadian scouts were unable to find any evidence that the rust had been introduced upon either pines or Ribes.

Little is known of the distribution of infection upon Ribes previous to 1922, except as it is indicated by the infection of pines. A little scouting was done late in the season of 1921 and some infection found upon cultivated black currants in the Puget Sound region near Port Townsend, Everett, and Mount Vernon, Wash. A great deal of scouting for the rust was done in 1922. Infection was found upon black currants in the Pemberton Meadows and near Mable Lake, B. C., and occasionally upon wild Ribes in many places in the Puget Sound region, near Forks, Grays Harbor, and in the vicinity of Willapa Bay, Wash. The black currant infections in the Willapa Bay region in the extreme southwestern part of Washington were fully 200 miles from the nearest known infection upon white pine and many miles from any 5-needled pines.

In 1923, infection was found upon susceptible wild Ribes in the Puget Sound region as far south as Chimacum, near Port Townsend. The cultivated black currants in this part of the State had been removed in 1922. No infection was discovered upon either the cultivated black currants or the wild Ribes in the Willapa Bay region. On the other hand, cultivated black currants were found infected at 26 places in the dry belt and the Columbia and Kootenay River Valleys in British Columbia.[9] On the coast infection was found at Namu and Bella Coola, 80 and 110 miles, respectively, north of the northern limit of white pine (*1*, *2*).[10]

WINDS IN THE NORTHWEST

The period of aeciospore production was found to be long and to vary considerably in different years. In 1922 aecia began to break open by the first week in May. The heaviest spore dispersal was between about May 15 and June 15. Considerable quantities of fresh aeciospores were found at Vancouver as late as July 5 and some were found in the mountains as late as July 18. In 1923, aecia began to break open the first week in April. The heaviest spore dispersal was between April 15 and May 15. Very few aeciospores were seen as late as June 29.

Possible agents for aeciospore distribution are winds, birds, animals, and man. It is scarcely conceivable that any considerable number of the Ribes infections in Washington or in British Columbia in either 1922 or 1923 could have been caused by spores carried by man. The large majority of the bushes had not been seen by any person who had been in the vicinity of infected pines before those bushes were discovered with infection. There are no other migrating animals which could have carried spores over the wide area in which infected Ribes were found.

Migratory birds move along the coast or north or south in the interior. They do not migrate east and west across the mountains. The species and subspecies of birds east of the Cascade Divide are largely different from those along the coast. It is very unusual to find a bird from the interior west of the Cascade Divide. Ribes infection in Washington was found before the migrating birds had returned from the north. The infections at Namu and Bella Coola are the only ones which by any stretch of the imagination could have been effected by birds. On the other hand, spores carried by winds may account for the infection wherever it has been found upon Ribes.

It is a well-known fact that the prevailing winds of the temperate regions of the earth's surface are from the west or southwest. Cyclones and anticyclones about centers of low or high barometric pressure cause temporary but more or less periodic variation in the direction and velocity of winds. The topography of the earth's surface

[9] See map for localities.

[10] LACHMUND, H. G. STUDIES ON WHITE PINE BLISTER RUST IN THE PACIFIC NORTHWEST. Report for 1923. [Unpublished. Typewritten copy in Office of Blister Rust Control, Bureau of Plant Industry, U. S. Dept. of Agriculture.]

causes local variation in the direction of surface winds. This is particularly marked in a broken country such as British Columbia and the Western States.

There is also considerable variation in the direction of wind in a given season in different years. For example, meteorological records for the northwest coast bear out the statements of close observers that a late spring and a dry summer are accompanied by an unusual aggregate of northerly winds. Tables IX and X show that in May and June the number of northerly winds, that is, those from the northeast, north, or northwest, at Seattle and Vancouver, is very considerable.

TABLE IX.—*Percentage of northerly winds at Seattle, Wash.*

Year	1917	1918	1919	1920	1921	1922	1923
May	28.8	23	30	27	43	27	26
June	36	49	42	34	27	44	41

TABLE X.—*Percentage of northerly winds at Vancouver, B. C.*

Year	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923
May	12	18.2	13.1	19.5	11.5	13	15.1	14.3	20.7	24.8	16.1
June	23	25.1	13.2	17	23.1	27.6	23	33.3	24.5	38.4	24

When taken in connection with Tables IX and X given above, the anemometer records for 1922 show fairly well the amount of wind movement from the different directions at representative stations in the region under consideration. Table XI shows the total number of miles which the wind traveled from each of the eight points during May and June of 1922:

TABLE XI.—*Anemometer records showing the number of miles which the wind traveled from each of eight points during May and June, 1922*

Station	Direction								
	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Total
	Miles	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*	*Miles*
Vancouver, B. C.:									
May	41	211	749	769	312	398	270	706	3,456
June	72	105	443	445	154	310	348	885	2,762
Steveston, B. C.:									
May	70	189	739	1,450	1,172	973	619	1,078	6,290
June	204	22	846	1,235	999	364	582	1,262	5,514
Victoria, B. C.:									
May	724	633	212	387	1,304	4,739	814	27	8,840
June	247	234	61	63	1,966	6,191	241	31	9,034
Summerland, B. C.:									
May	904	303	510	1,168	430	865	716	1,164	6,060
June	1,350	99	83	571	83	1,273	720	2,497	6,676
Seattle, Wash.:									
May	1,103	626	383	825	2,246	1,468	531	307	7,489
June	1,119	523	14	375	1,253	717	661	730	5,392
Portland, Oreg.:									
May	702	199	832	197	561	827	685	2,094	6,097
June	1,082	76	29	127	184	177	185	2,144	4,004
Roseburg, Oreg.:									
May	811	139	28	34	167	346	271	694	2,490
June	1,381	89	31	6	22	60	130	636	2,355
Red Bluff, Calif.:									
May	1,060	36	19	1,045	246	38	291	2,213	4,948
June	323	40	112	1,665	866	50	34	529	3,619
San Francisco, Calif.:									
May	207	81	28	105	77	1,615	4,788	776	7,677
June	-------	32	20	36	23	1,581	5,420	88	7,200

The Victoria and San Francisco stations are in exposed situations and record more of the prevailing winds of the coast. The Vancouver and Roseburg Stations are in more sheltered situations and, consequently, record less of the prevailing winds. The latter do, however, give a good record of local and surface winds.

Anemometer records, as well as the recorded observations of many weather bureau observers, show that the Strait of Georgia, Washington Sound, and Puget Sound form a very favorable channel for the movement of a wide current of air from the northwest down into the interior and southwestern part of Washington. There are periods of one to several days with continuous northerly winds. Between May 26 and June 26, 1922, the Seattle records show that there were three such periods with winds, as follows:

	N.	NE.	E.	SE.	S.	SW.	W.	NW.
May 26–31	502	207	186					60
June 15–18	227	298	3			6	89	143
June 23–26	321	82				3	70	200

The continuity of the surface winds is interrupted by cross currents caused by mountains and valleys below, and by countercurrents in the upper atmosphere. The valley of the Columbia River causes particularly strong currents to the east or west. Pilot balloon records at Camp Lewis, Wash., show that for June, 1922, the direction of the prevailing winds at the surface was northwest and that above 1,500 feet elevation the prevailing direction was southwest. Rarely would it be possible for the same body of air to move from the Strait of Georgia across Washington into Oregon. There was, however, one brief period, June 16 and 17, 1922, when this might have occurred. During these two days there were 502 miles of northerly wind at Seattle, Wash., and 453 miles at Portland, Oreg. The pilot balloon at Camp Lewis showed for June 17 a continuous north wind up to an elevation of 5,000 feet.

In a similar manner the air moves southward over western Oregon, especially along the Willamette Valleys into southern Oregon and northern California. Although there are more intervening valleys and mountains here than in the north, their influence is offset by the relatively greater number of north winds.

Between the Cascades and the Rocky Mountains, wind movements are similar to those west of the Cascades. The anemometer records for Summerland, B. C. (Table XI) may be taken as fairly representative for the valleys which extend north and south in the interior and southeastern part of British Columbia. Observations made twice each day at Nelson, B. C., give the frequency of the winds at that station for 1922 as follows:

Direction	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm	Total observations
May	1	7	4	12	1	5	8	17	7	62
June	4	2	2	6	1	2	12	16	15	60

Although there are no anemometer records for northeastern Washington and northern Idaho, the eye observations by meteorologists in that part of the country indicate considerable northerly wind in the north and south valleys. There is probably as much northerly wind at any one place in these valleys as in Puget Sound. They are, however, relatively narrow. The country is more broken, and the daily range of the temperature is greater. These factors all tend to break the continuity of air currents and make it improbable that they can flow continuously in the interior as far as they do along the Strait of Georgia and Puget Sound. It should be noted that Summerland is in the dry country between the white pine belts and that there is a greater amount of northerly wind in the dry belt than in country farther east. The continuity of northerly winds down the Arrow Lake Valley is broken by cross currents at Nelson.

PRECIPITATION IN THE NORTHWEST

Infection of Ribes and probably nearly all infection of pines is dependent upon moisture conditions during the summer months. This statement is based largely upon the writer's observations and experiments upon the rust in the Eastern States. In some localities near the coast fog may be an important factor. Precipitation records, however, have been found to indicate very well the moisture conditions in any given locality, that is, with a few exceptions, the total precipitation for a month indicates fairly well the favorableness of the weather during that month for the development of the rust.

Precipitation records (Table XII) for Vancouver are representative of the moisture conditions for practically all the coast region in which the rust has been found. They also illustrate very well the variation in amount which may be expected in different years at any place in the white pine country (Tables XIII to XVI).

TABLE XII.—*Precipitation, in inches, of rainfall for June, July, and August at Vancouver, B. C.*

Year	June	July	August	Total
1913	3.75	2.02	0.85	6.62
1914	3.58	.42	.75	4.75
1915	.91	.91	.36	2.18
1916	1.34	5.35	.58	7.27
1917	5.40	.48	.93	6.81
1918	1.00	2.20	4.50	7.70
1919	.98	.15	1.15	2.28
1920	3.08	.67	2.91	6.66
1921	3.64	.32	.84	6.80
1922	.17	.02	2.01	2.20
1923	2.08	.52		

TABLE XIII.—*Average summer precipitation, in inches, for stations at or near which infection has been found upon pines*

	June	July	August	Total or average for season
Agassiz, B. C.	4.54	2.05	2.55	9.14
Blaine, Wash.	2.12	.88	1.22	4.22
Enderby, B. C.	2.06	1.29	1.21	4.56
Ferguson, B. C.	2.64	2.01	2.06	6.71
Pemberton, B. C.	1.46	.97	1.51	3.94
Revelstoke, B. C.	2.69	2.49	2.49	7.67
Vancouver, B. C.	2.59	1.31	1.74	5.64

TABLE XIV.—*Average summer precipitation, in inches, at stations in the inland region of white pine*

	June	July	August	Total or average for season
Cranbrook, B. C.	1.62	1.51	0.93	4.06
Enderby, B. C.	2.06	1.29	1.21	4.56
Ferguson, B. C.	2.64	2.01	2.06	6.71
Nelson, B. C.	2.44	1.70	1.51	5.65
Revelstoke, B. C.	2.69	2.49	2.49	7.67
Rossland, B. C.	2.33	1.38	1.23	4.94
Priest River, Idaho	1.73	1.13	1.17	4.03
Kellogg, Idaho	1.99	1.10	1.07	4.16
Wallace, Idaho	2.15	1.13	1.21	4.49
Dayson, Mont.	2.35	1.25	1.22	4.82
Fortine, Mont.	2.71	1.52	1.48	5.71
Heron, Mont.	1.89	1.46	1.22	4.57
Polson, Mont.	2.22	1.17	.93	4.32

TABLE XV.—*Average summer precipitation, in inches, at stations in Western Washington, Oregon, and Northern California*

	June	July	August	Total or average for season
Aberdeen, Wash.	3.36	1.17	1.06	5.59
Cedar Lake, Wash.	5.23	2.34	2.48	10.05
Glenoma, Wash.	2.43	1.17	1.50	5.10
La Center, Wash.	2.36	.95	1.06	4.37
Quinault, Wash.	5.29	1.53	2.17	8.99
Sedro Woolley, Wash.	2.68	1.46	1.70	5.84
Cascade Locks, Oreg.	2.39	.80	.92	4.11
Cascadia, Oreg.	3.16	1.04	1.05	5.25
Government Camp, Oreg.	3.28	1.58	1.90	6.76
Prospect, Oreg.	1.44	.66	.32	2.42
Grants Pass, Oreg.	.85	.17	.23	1.25
Jacksonville, Oreg.	.96	.33	.32	1.61
Medford, Oreg.	.84	.43	.13	1.40
Montague, Calif.	.75	.45	.20	1.40
Sisson, Calif.	.62	.16	.30	1.08
Summit, Calif.	.56	.22	.11	.89

All available data show somewhat less summer precipitation in the "Inland Empire" and in the greater part of western Washington than in the coast region of British Columbia. The amount of precipitation for the summer months diminishes southward. In southern Oregon and northern California many seasons have no precipitation during the summer season. Table XVI, precipitation for Summit, Calif., represents the conditions at nearly all places in the sugar-pine country. This shows that rarely is there a summer with precipitation equal to that of the driest of the British Columbia stations at which the rust has been found.

It is to be noted that, as a rule, the summers with the greatest amount of northerly wind have the least precipitation.

TABLE XVI.—*Precipitation, in inches, during June, July, and August, 1871 to 1922, inclusive, at Summit, Calif.*

	June	July	August	Total
1871	0.89	0.00	0.00	0.89
1872	.00	.00	.00	.00
1873	.00	.03	Trace	.03
1874	Trace	.00	.00	
1875	2.55	Trace	.00	2.55
1876	Trace	1.21	.10	1.31
1877	.12	.00	.00	.12
1878	.00	.00	.09	.09
1879	.10	.00	.00	.10
1880	.00	.80	.00	.80
1881	.50	.00	.00	.50
1882	.00	.00	.00	00
1883	.00	.00	.00	.00
1884	4.04	.00	.00	4.04
1885	.80	.00	Trace	.80
1886	.00	.00	.00	.00
1887	1.60	.10	Trace	1.70
1888	3.72	3.51	.28	7.51
1889	.22	.00	.00	.22
1890	.00	.00	.00	.00
1891	.00	.00	.00	.00
1892	.20	.00	.00	.20
1893	.00	.00	.00	.00
1894	.00	.00	.00	.00
1895	.00	.00	.00	.00
1896	.00	.21	.02	.23
1897	0.70	0.00	0.00	0.70
1898	.90	.00	.00	.90
1899	.70	.00	1.00	1.70
1900	.50	.25	Trace	.75
1901	.00	.00	.00	.00
1902	.30	.00	1.00	1.30
1903	Trace	.00	.00	
1904	.05	.04	.03	.12
1905	1.40	Trace	.00	1.40
1906	2.10	Trace	1.00	3.10
1907	2.22	.12	Trace	2.34
1908	.44	.00	.76	1.20
1909	.88	.00	.00	.88
1910	.00	1.16	.00	1.16
1911	.04	.00	.00	.04
1912	.20	.30	.00	.50
1913	.05	2.45	.15	2.65
1914	1.19	.00	Trace	1.19
1915	.00	.55	Trace	.55
1916	.05	.50	Trace	.55
1917	.00	.00	.21	.21
1918	.15	.00	.16	.31
1919	.00	.00	.00	.00
1920	1.60	.00	.67	2.27
1921	.57	.00	.00	.57
1922	.78	.00	.00	.78

DISCUSSION

The prevailing winds and the distribution of precipitation through the summer months have favored the spread of the white pine blister rust in the coast region of British Columbia to the north and northwest, as well as along the valleys to the north and east through the Cascade Mountains. Although aeciospores have been produced in increasing numbers since 1913, at least, and there have been winds sufficient to carry them long distances in every direction, it is apparent that but one season in four has been favorable for any considerable spread of the rust. There was a little infection in the other years. This occurred, however, only in the immediate vicinity of Ribes growing near pines with fruiting cankers.

It is not difficult to understand why very little infection occurred in the years with light summer precipitation, as 1915, with a total of 2.18 inches and 1919 with 2.28 inches, as compared with the average of 5.64 inches, and 6.81 inches for 1917 or 6.80 inches for 1921. On the other hand, it is not easy to see why infection was not greater in other years with a fairly high summer precipitation. In this connection it is necessary to note the requirements for general or heavy infection.

Heavy precipitation in the period of aeciospore production has been observed to reduce greatly the dispersal of spores by washing them out of the aecia. In moist weather many of the aeciospores germinate within the aecia. Their germ tubes then prevent or retard the dispersal of the remaining spores.[11] After the spores are deposited upon Ribes leaves there must be a period with sufficient moisture to permit them to germinate and invade the leaf tissue. After uredospores begin to form there must be occasional moist periods to permit further infection of the leaves if there are to be any considerable number of telia produced. After telia are produced there must be a period favorable for the production of sporidia and the immediate infection of pine needles.

The production of sporidia and the infection of the pine needle seems to be a most critical point in the life history of the rust. York and Snell (*10*) found that a continuous period of 18½ hours with a practically saturated atmosphere is necessary to secure infection of the pine needle. The sporidia are delicate and short-lived. Whatever the combination of circumstances or causes may be, it seems to be a fact that little infection of pine will result in the year with a very dry summer. It is also true that heavy infection does not always occur in years with normal or more than the normal summer precipitation.

The infection in the interior of British Columbia at Canoe, Revelstoke, and Beaton can scarcely be attributed to any other source than wind-borne aeciospores from the coast. The infection at Nakusp may have resulted in the same way or by aeciospores carried down the Columbia Valley

[11] From the author's unpublished manuscript.

from Beaton or Revelstoke. These places are all in the path of the prevailing winds from the coast. There are frequently strong surface winds which blow up through the valley along the Pacific Great Eastern Railway and over the divide into the interior.

The widespread infection of black currants in 1923 at many places in the dry belt, as well as to the east of it, is further evidence of wind dissemination. A glance at the map shows that these places also are all east of the region of heavy pine infection and in line with the prevailing westerly winds from the coast.

The widely distributed infection of Ribes in western Washington in the season of 1922 must have been caused by long-distance spread of aeciospores from British Columbia. This was made possible by the enormous number of spores produced through an unusually long season, from the middle of May until the middle of July, and by the unusual amount of northerly winds at certain periods which came down the Strait of Georgia, through Puget Sound, and spread over the country to the south and west.

All the evidence seems to indicate that long-distance spread of the rust has been caused by wind-borne aeciospores. The only remaining explanation requires long-distance spread by uredospores or a gradual spread and overwintering upon Ribes. Long-distance dissemination of uredospores would be much more remarkable than long distance dissemination of aeciospores. All field studies made by the writer in the East as well as in the West fail to show any considerable spread of the rust by uredospores (*6*). Overwintering upon *Ribes nigrum* has been demonstrated twice under experimental conditions. On the other hand, many experiments have given negative results. Field observations have never shown that the rust has overwintered upon either cultivated or wild Ribes (*8, p. 68–71*). The rust did not survive the winter of 1922–23 upon *R. nigrum* in the Willapa Bay region of southwestern Washington. The bushes on four plantations, all heavily infected in 1922, failed to show any infection in 1923. These were examined in June and again the last week in August. All the other *R. nigrum* in this part of the State were eradicated in 1922. The plants in question were to be destroyed in the autumn of 1923.

It is very improbable that these spores came from local pine infections in Washington. The distribution of the infected Ribes indicated a distant source of spores. If the spores did not come a long distance there must have been many local centers of infection. Thorough scouting, however, failed to show any fruiting cankers in Washington. Many of the infected Ribes, particularly those in the Willapa Bay region, were long distances from any five-needle pines. (See figs. 1 and 2.)

Aeciospores are well adapted for dissemination by air currents. They are dry and powdery and retain their vitality for many days or weeks under adverse conditions. Smut spores are known to be carried long distances by wind (*4*.) Spores of wheat rust have been found over 10,000 feet above the surface of the earth (*9*).[12]

All the species of Ribes found in British Columbia were in a dormant condition and without leaves by the middle of December, 1922, and they so remained until April, 1923. In February, 1923, many plantations of *Ribes nigrum* were examined in Washington and in Oregon as far south as Ashland. All were found to be perfectly dormant, without leaves and with no buds opening. Below Roseburg, Oreg., some wild Ribes were found with a few green leaves of 1922, and buds beginning to open. All the Ribes seen in Washington were in a dormant condition at that time. It has been reported, however, that *R. sanguinium* as far north as Seattle holds a few of its old leaves until the next season's buds open. It appears that the chances for overwintering were very slight even if there had been uredospores upon the old leaves. Many infected *R. nigrum* leaves collected late in October and in November, 1922, were examined. No uredospores, however, could be found upon them.

In the vicinity of Port Townsend, infection was found again in 1923 upon Ribes in the same locality in which it appeared in 1922. In one instance the same plants of *R. bracteosum* and *R. divaricatum* were found with infection in 1922 and in 1923. These were some 9 or 10 miles from the *R. nigrum* which were found infected in 1921. This place is near Puget Sound, less than 80 miles from infected pine in British Columbia. It is altogether probable that these plants as well as many others in favorable situations upon Puget Sound may become infected each year by aeciospores from

[12] Since this paper was submitted for publication, J. A. Larsen (*5*) has called attention to wind dissemination of dust from Oregon and Washington to northern Idaho and Montana.

British Columbia. The probability of overwintering of *Cronartium ribicola* does not seem to be greater in the Northwest than in the Northeastern States.

It is not easy to predict accurately how rapidly the rust will move southward either west of the Cascades or in the "Inland Empire." Its history indicates that its spread upon pine to the south is relatively slow, not over 40 miles since it was introduced into Vancouver in 1910. The fact that north winds accompany dry seasons seems to be an important factor favoring a slower spread of the rust toward the south. On the other hand, *Ribes nigrum*, and to some extent other species of Ribes, may become infected in dry seasons like 1922, and a little pine infection may occur. The volume of aeciospore production is increasing each year in British Columbia. Infection has appeared in the Puget Sound region for at least three years in succession. It is practically certain, therefore, that the rust will become established in western Washington within a few years. When it is once established there, and aeciospores are produced in considerable quantities, it will tend to spread into and through the Cascades to the north and east. Aeciospores may then be carried southward into Oregon and when it becomes established there north winds may carry aeciospores into southern Oregon and northern California.

Although it is scarcely possible that much, if any, infection may occur in the sugar pine region (fig. 1) during the usual dry season, it is very probable that abundant infection may occur in the occasional wet summers such as those of 1888, 1906, and 1913. This possibility is emphasized by the presence of a similar rust, *Cronartium pyriforme*, upon the yellow pine in northern California.

The white pine in the "Inland Empre" is in line with the prevailing winds from the coast. It is also in line with local currents which move southward along the Columbia and Kootenay Valleys. The spread of infection in 1923 to *Ribes nigrum* in the interior of British Columbia and northeastern Washington shows that spores of the rust are practically certain to be carried into the white pine regions of Idaho and Montana. When this happens, infection of pine will depend upon moisture conditions and the presence of susceptible Ribes.

Comparison of the summer precipitation at various stations (Tables XII, XIII, and XIV) in the white pine districts shows less summer rainfall in the interior of British Columbia than upon the coast. It also shows less for Idaho and Montana than for places farther north in British Columbia. The average summer precipitation for these three districts is as follows.[13]

	Inches
Coast region of British Columbia	6.58
Interior of British Columbia	5.93
Idaho and Montana	4.68

These figures indicate, other conditions being equal, that infection of pine should be less severe in the interior than upon the coast of British Columbia. The relatively small amount of infection thus far discovered in eastern British Columbia seems to substantiate this claim (see Table VIII). For the same reason infection should become established more slowly and be less severe in Idaho and Montana than in eastern British Columbia.

The destruction of all infected pine material which has been found in eastern British Columbia should tend to retard the spread of the rust.

It is a significant fact that all the pine infection in eastern British Columbia can be attributed to *Ribes nigrum* and that practically all the infected Ribes found in the dry belt or east of it were this species.

Climatic factors can not be changed materially by man, but the elimination of *Ribes nigrum* from the pine districts of Idaho and Montana should lengthen greatly the time before the rust becomes established in these States.

SUMMARY

The white-pine blister rust has been in British Columbia at least since 1910.

It became widespread by 1913.

It has spread upon the white pine practically to the north and east limits of the coast belt of white pine.

It has spread a relatively short distance to the south.

It has become established at four places in the eastern belt of white pine in British Columbia.

An average of one season in every four years has been favorable for general spread of the disease along the coast of British Columbia.

In the summer of 1922 there was infection of Ribes by aeciospores as far south as Ilwaco, Wash. In 1923 infection was not found south of the vicinity of Port Townsend, Wash.

[13] These figures were obtained by taking an average for the six stations in each district with the greatest summer precipitation. The data for British Columbia is from "Climate of British Columbia," by F. Napier Denison (*5*).

In 1923 infection was found on Ribes at Namu and Bella Coola, 80 and 110 miles, respectively, north of the limit of white pine upon the coast.

Prevailing westerly winds favor aeciospore dispersal from the coast toward the east.

Northerly winds, which favor aeciospore dispersal to the south, are most common in dry seasons, which are unfavorable for pine infection.

West of the Cascades, northerly winds in the period of aeciospore production increase to the southward as far as northern California.

The amount of summer precipitation diminishes southward.

The rust is practically certain to spread southward at a much slower rate than to the north and east.

The spread of the rust to the "Inland Empire" may be greatly retarded by the elimination of *Ribes nigrum* from that region.

LITERATURE CITED

(1) DAVIDSON, A. T.
1922. WHITE PINE BLISTER RUST IN BRITISH COLUMBIA (REPORT ON CANADIAN CONDITIONS AND WORK). Rpt. Proc. & Rec. Western White Pine Blister Rust Conf. 3: 9–22. [Mimeographed]

(2) ——
1924. RESULTS OF PAST SEASON'S WORK, PRESENT SITUATION AND FUTURE PLANS. Rpt. Proc. Meeting Trust. Western White Pine Blister Rust Conf., Spokane, Wash., Jan. 7–8, 1924. [Mimeographed]

(3) DENISON, F. N.
1923. CLIMATE OF BRITISH COLUMBIA. Brit. Columb. Dept. Agr. Bul. 27, 15 p.

(4) HEALD, F. D., and GEORGE, D. C.
1918. THE WIND DISSEMINATION OF THE SPORES OF BUNT OR STINKING SMUT OF WHEAT. Wash. Agr. Exp. Sta. Bul. 151, 23 p., illus.

(5) LARSEN, J. A.
1924. DUST STORMS OF NORTHERN IDAHO AND WESTERN MONTANA. Jour. Forestry 22: 576–577.

(6) SNELL, W. H.
1920. OBSERVATIONS ON THE DISTANCE OF SPREAD OF AECIOSPORES AND UREDINIOSPORES OF CRONARTIUM RIBICOLA. Phytopathology 10: 358–364.

(7) SPAULDING, P.
1911. THE BLISTER RUST OF WHITE PINE. U. S. Dept. Agr., Bur. Plant Indus. Bul. 206, 88 p., illus.

(8) ——
1922. INVESTIGATIONS OF THE WHITE PINE BLISTER RUST. U. S. Dept. Agr. Bul. 957, 100 p., illus.

(9) STAKMAN, E. C., HENRY, A. W., CURRAN, G. C., and CHRISTOPHER, W. N.
1923. SPORES IN THE UPPER AIR. Jour. Agr. Research 24: 599–606, illus.

(10) YORK, H. H., and SNELL, W. H.
1922. EXPERIMENTS IN THE INFECTION OF PINUS STROBUS WITH CRONARTIUM RIBICOLA. Phytopathology 12: 148–150.

THE CONSTRUCTION OF TAPER CURVES [1]

By FREDERICK S. BAKER

Forest Examiner, Forest Service, United States Department of Agriculture

INTRODUCTION

Among the first requisites of a forester's equipment in estimating standing timber are accurate and dependable volume tables, applicable to the stands being estimated and the utilization expected. Such tables show, in general, the average volume (in board feet, cubic feet, or other units of measure) of trees of different diameters and heights. It has not proved easy to construct dependable tables of this kind, owing to the difficulty of determining accurately the average volume of trees in the unusual size classes represented by very tall, slender trees and very short, large trees, for it is difficult to discover specimens enough of these classes to furnish the basis of reliable averages.

The first volume tables to be used were constructed simply by scaling a large number of trees of different sizes, averaging the scale of all trees in the same diameter and height class and then harmonizing the values for the different height classes as well as possible by graphic methods. This was the method described in 1906 by Graves (*9, p. 158–163, 166, 167*).[2] It is slow, requires a large mass of data, and the graphic harmonization necessary to make values run smoothly often introduces grave inaccuracy.

In 1915, Barrows (*1, 2*) described a new method, which introduced taper curves, or curves showing the average form of trees, as a step in volume table construction. This was a great improvement over the earlier systems, and has been very generally used since that time. The method was accepted as undoubtedly sound and effective, the results were believed to be entirely satisfactory, and much time and labor were put in on the tedious series of curves necessary in this method. The present writer, however, in making a series of taper curves for lodgepole pine on a slender basis of trees, discovered that very palpable errors had come through the whole series of harmonizations and that the final curves were not dependable. This has led to an analysis of the underlying theory of Barrows's series of recurvings, and to the conclusion that the latter are not as satisfactory as they would appear to be on the surface. It is no new discovery that errors exist in this method of handling taper curves. Barrows himself admits the fundamental error, that taper curves give not the average volume of the trees in any group, but the volume of the tree of average dimensions.

In finding average tree form, diameters are averaged; in the earlier method, volumes proportional to diameters squared were averaged. The error introduced depends upon the range of values in a given class, but, as pointed out by Barrows, it never becomes serious. Bruce (*4*) implies more grave dangers by demonstrating the presence of errors in certain volume tables undoubtedly built up according to Barrows's method. He shows that in these tables the values vary erratically from the volumes of the frustums of cones having the same top diameters and the same breast-high diameters as the trees; a divergence that can not possibly be true if the values pretend to represent true means. The cause of this variation, however, was never determined by Bruce, which leaves an uncertainty as to just what is wrong with taper curves, and whether the difficulty is remediable or not.

NATURE OF UNHARMONIZED TAPER CURVES

In analyzing Barrows's method and the errors inherent in it, consideration must first be given to the basic data from which the taper curves are drawn. These consist of individual tree records giving diameter, usually by regular intervals (often 8 or 16 feet) from the stump to the top of the tree. Height is given to the nearest tenth of a foot; diameter to the nearest tenth of an inch. The size classes which are used as the basis of all computations, and which appear in the final volume tables

[1] Received for publication June 30, 1924; issued June, 1925.

[2] Reference is made by number (italic) to "Literature cited," p. 624.

are usually based on 1-inch diameter intervals and 10-foot height intervals. For example, a tree 14.7 inches in diameter at breast height and 82.2 feet tall, belongs in the 15 inch–80 foot class. Trees are usually well distributed as to diameters within a given inch and height class so that the average of all trees falling in such given class is very close to the assigned even diameter. Of course, for each height class there is a mean diameter from which the diameter values fall away on each side roughly in accord with the laws of chance. This curve is long and flat, however, for diameters in any height class, and the distribution of diameters through any single inch class is virtually even, although, of course, theoretically not quite so in any but the model class. Thus, in the 12-inch d. b. h. class, individual trees will range from 11.6 to 12.5 inches d. b. h. Unless there are very few trees indeed in the class, in practice the mean will always fall very close to 12.0 inches. Only occasionally in the highest and lowest diameter classes will this rule fail, as it may indeed by chance in any class represented by a very few trees.

Conditions are not the same, however, in regard to the height. Trees of the same inch class may be tall, short, or medium, and a very wide variation of height values is possible, ranging from two-thirds to one-half of the total height of the trees, in lodgepole pine at least. This variation is very nearly "normal," that is, the heights vary from the central or modal value according to the laws of chance. In case, therefore, the entire sample of data relating to a single inch class is subdivided into five smaller classes on the basis of height, the central class will have evenly balanced values and the actual average will generally represent the true mean of the class. The next class adjacent both above and below will have its values piled up asymmetrically, with a preponderance of values nearer the average height for the inch class. For example, suppose there are five height classes, 100, 90, 80, 70, 60 feet, as shown in Figure 1. The average height of all trees in the central class, 80 feet, will be 80 feet. In the 90-foot class there will tend to be more 86-foot trees than 94, and the average height of the 90-foot class will be lower, perhaps about 88 feet. Conversely, in the 70-foot class values will tend to run high. In the outermost classes this effect is still more pronounced and the average 100-foot tree may be only 96 feet tall, while the average 60-foot tree may be 64. If the tables were to be used only in the region where prepared, this would be of little moment, for in the timber estimate 100-foot trees would again average 96 feet tall and the volume of 96-foot trees would be the correct volume to use. In a region where sites were better, however, trees in the 100-foot class might be 100 feet tall and volumes based on 96-foot trees would be low.

It must be the aim of taper curves and volume tables to give the true middle values of the class represented, or else they will be meaningless. Therefore, the values of the 15 inch–100 foot tree class must be exactly right for trees 15 inches in diameter, and 100 feet tall, and not perhaps for a tree 14.8 inches d. b. h. and 96.7 feet in height. One qualification of any system of volume-table construction must be its ability to take these values that fall a little from the middle of the class they represent and bring them into their proper places.

When diameters taken at intervals up the tree are averaged in each diameter and height class, as is the first step in the preparation of taper curves, there is some question as to the value these averages have and how nearly they truly represent the midtree of the class. This apparently simple operation is not without its complexities.

Sometimes in getting average diameters well toward the top it will be found that certain trees "drop out." For example, if the diameter 78 feet from the base in the 80-foot class is being sought, some trees will "drop out," being less than 78 feet tall and yet over 75 feet tall, and therefore still in the 80-foot class. In averaging they usually are given a value of zero, but it is easily seen that they have a potentially minus value. So, where some of the trees have "dropped out" average diameters are too high. It is well to disregard measurements of diameters at heights where all the trees in the class are not represented, as they lead to error rather than accuracy.

Aside from these mathematical points is the natural fact that the greatest variability in trees is toward the tops. In any given inch and height class the diameter of the trees will vary little more than an inch between maximum and minimum diameters 8 feet above the ground, and perhaps about 2 inches at 16 feet up; while 72 feet up in an 80-foot height class the diameters may range over 5 or 6 inches in variance even in smooth normal trees. Almost every mass of field data contains abnormal trees measured too near swell-

ings, large limbs, forks, etc., which all contribute to wide variability upward. These factors in turn lead to mean diameters containing large probable errors, so much so that when a series of them in consecutive size classes is compared, a great lack of harmony is always found, the amount depending chiefly upon the number of tree measurements used as a basis.

HARMONIZING THE CURVES—BARROWS'S METHOD

Having examined the shortcomings of the original data, the next step is to see how the method of compilation gets around them.

but may vary from the exact even inch; although, as already pointed out, this is unusual, except where only a small number of trees are measured. Average height may also, and very frequently does, fall on one side or another of the exact middle point of the height class as shown in Figure 1. Nowhere does Barrows intimate that this occurs, although he particularly points out the more infrequent case of the average tree failing to fall on the even inch of the proper d. b. h. class.

One fact that helps to prevent the errors in the upper parts of taper curves from becoming extremely serious is the stability of the end point derived from averaging the total heights of the trees.

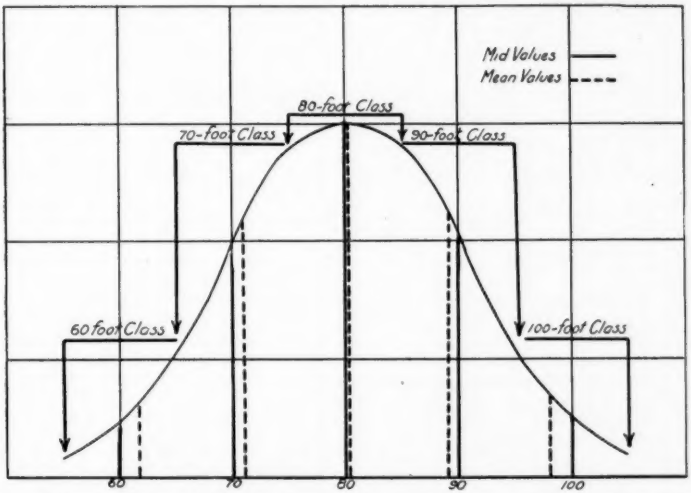

FIG. 1.—Difference between midvalues in various height classes and actual average values due to asymmetrical distribution of values

The conventional method of Barrows consists of several series of curves, of three primary forms shown in Figure 2 in a somewhat simplified form, conical trees and straight lines being used to show more clearly certain points.

The first series of curves, exemplified in Figure 2, A, is drawn through points representing the average diameters at different heights, as compiled from the original tree measurement sheets. All trees of various diameter classes are thrown into one chart, a separate chart being made for each height class. Drawing curves through the plotted points serves to iron out minor irregularities of form and makes the average tree a smooth curve. These curves do not necessarily pass through the exact middle value of each d. b. h. class. At the same time the possibility of errors in the higher parts of all curves presents a considerable problem. Such errors all contribute to irregularities and peculiarities of shape in individual curves which can only be properly straightened out by an efficient method of harmonization.

Figure 2, A, shows the first series of curves simply by the use of straight lines. Accepting Barrows' statement, they are shown failing to pass through the middle value in each inch class (the even inch) at breast height, but at present for simplicity's sake are assumed to converge exactly at the 70-foot point.

The second series of curves is shown in Figure 2, B. In this series of curves the d. b. h. of the tree is made the

abscissa, and the diameter at other points the ordinate. As a rule, values are read at 10-foot intervals up the tree from the curves of series A, and a separate curve is drawn showing the relation of d. b. h. to diameter, 10, 20, 30, and 40 feet above ground level. This series of curves so rounds out the values in Figure 2, A, that, in effect, it takes the lines as shown in Figure 2, A, and turning them upon the point of convergence as a pivot spaces them systematically, placing them upon the correct d. b. h. If the lines in Figure 2, B, are straight, the corrected spacing of the lines in Figure 2, A, will be even; if they are curves, the spacing will be uneven, but the changes will be regular and even (as will occur in cases where form changes with diameter). In practice, lines in Figure 2, B, are nearly straight. Their slope depends upon the distance between the lines in Figure 2, A, at various levels, so there is the greatest slant at the base of the tree where the lines are farthest apart and the least toward the tip.

The spacing between the lines in Figure 2, B, depends upon the slope of the lines in Figure 2, A (taper of the trees). In conical trees they are naturally evenly spaced, as shown in the figure, but in full-boled trees they get farther and farther apart toward the top of the tree, as in such trees rate of taper increases upward. In practical work, the points determining these lines usually fail considerably of falling into good lines, so that in drawing an average curve errors are very likely to be made in giving end values with a poor basis more weight than they deserve, consequently tilting the lines. Marked tilting in any single line will be noticed on inspection of the finished graph, however, unless all the lines are tilted in the same direction (which unfortunately is quite possible). The effect is equivalent to making the lines in Figure 2, A, evenly spaced, but either too far apart or not far enough. The spacing may be different in different height classes, as these are curved entirely independently.

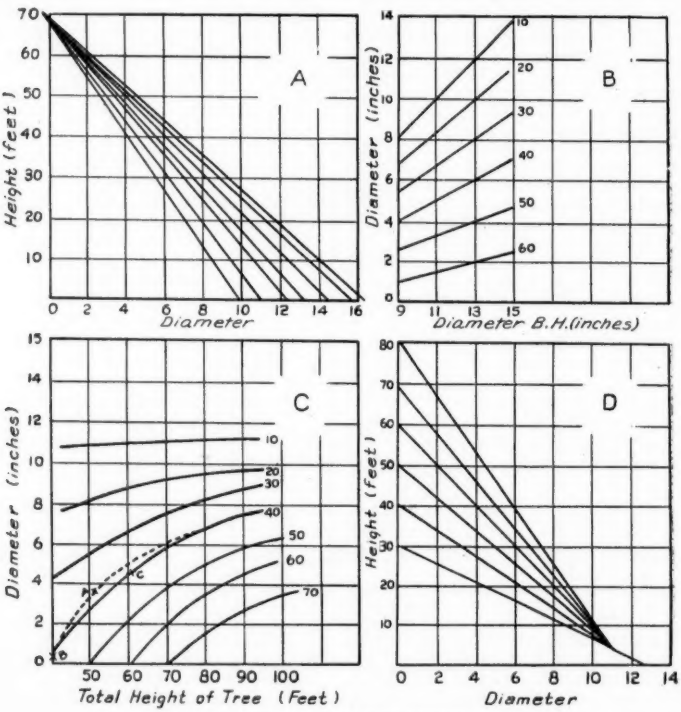

FIG. 2.—The main steps in graphic harmonization of taper curves

The third system of curves is aimed to harmonize values in the same d. b. h. class, but in different height classes. There are never many height classes in a single d. b. h. class, for the variation in the height of trees of a given diameter never amounts to many ten-foot intervals (the usual classification). The curves are, therefore, short and more open to error in direction than long curves. Their form is illustrated in Figure 2, C, and their function is similar to curves of the second series as shown in Figure 2, B, except that d. b. h. is constant instead of the height of the tree, and separate charts are drawn for each d. b. h. class. Their shape is different, however. In Figure 2, A, it is clear that the normal distribution of the lines is fairly evenly spaced across the sheet, at any given height, hence their relation is expressed by very nearly a straight line. In Figure 2, D, the spacing is even, but up and down rather than horizontally across the page. Curves as shown in Figure 2, C, however, if properly drawn, ought to have the effect of arranging the lines *harmonically* across the page, as is desired.

If these curves are not properly drawn they lead to a variety of errors. If the curve is the wrong shape (provided the end points are right) it means that in trees of medium height the diameters are incorrect. Curves which touch the basal line fortunately have one point fixed, for diameter at the top of a tree must always be zero. The curves representing points 10 and 20 feet above the ground approximate straight lines and diverge but slightly, but higher curves are difficult to draw. In the first place, the values high in the tree are erratic, for reasons that will be shown later, and the curvings in series B do not remedy matters very much. Secondly, these points are incapable of much correction by the curves, for the change of direction is rapid at that point, divergence is considerable, and the curves are widely spaced, all of which renders the proper placing and shaping of the curve very difficult.

In practice it is found that the curves are most naturally drawn to pass through the point plotted to represent diameter 10 feet from the top, while actually such points often need severe correction. An error in diameter 10 feet below the top may not exist in one diameter class alone, as such a possibility has already been ironed out in the curves of Figure 2, B. Consequently, curves of Figure 2, C, pass it on, although theoretically they ought to remove it. For instance, in Figure 2, C, let us suppose the diameters of all the trees in the 50-foot class at the 40-foot point are high because of the misplacement of the 40-foot line in the previous curving of the type shown in Figure 2, B (for the regularity of the spacing of these lines is difficult to judge on a large scale). Then in Figure 2, C, the point A will fall high at the 40-foot point. In 40-foot and 60-foot tree classes (points B and C) the values we will suppose to be correct. Nevertheless, because of the rapid curvature, lack of parallelism and width of spacing in that part of the graphs, it is hard to make a choice between the solid line or the dotted line as shown in the figure, one confirming an erroneous value and changing a correct one, the other changing the wrong value to the right one. Curves of the form shown in Figure 2, C, serve to even up the erratic values, however, especially in tall trees and in the lower part of the bole, and to make changes run smoothly from height class to height class within the same inch class.

As each inch class is adjusted separately, there is no assurance that the same relative adjustment will be made in the neighboring inch classes. Accordingly, values are read back again to make curves of the type shown in Figure 2, B, where the inch classes are again put in harmonious relations with each other, with some possible disarrangement of ideal relations existing between the different height classes. These curves are finally transformed back again to curves of the type shown in Figure 2, A, the finished taper curve.

Having briefly outlined the method and noted some of the difficulties encountered, its practical effectiveness must be considered. The first curving makes the form of the trees in each diameter and height class independently smooth, although their forms may differ. This is good. Next, the lines are spaced evenly and are made to run through the right d. b. h. through the process shown in Figure 2, B. But although spaced evenly, what is the assurance that the spaces are the right distance apart? If wrong in a single height class, curves of series 3 (fig. 2, C) will tend to iron out the trouble when the erroneous value is placed in comparison with correct values in adjacent classes. But just here is where one error comes in.

In practice, the first curves fail to converge as they are shown doing in

Figure 2, A, upon the exact height class. Seventy feet may be tall for 9-inch trees and the average height of the 9 inch–70 foot class may be only 67 feet. Likewise, 70 feet may be short for a 16-inch tree and the average height may be 72 feet. So, ultimately, in a given diameter class, short trees are forcibly stretched out to the mean of their height class and tall trees are pulled down to the mean of the class, as already brought out and shown in Figure 1 and Figure 3 A, an idealized form of Figure 2 D, which leads to a distortion of form.

In practice, in drawing the first curves of the form shown in Figure 2 A, an irregular jumble and crisscross-

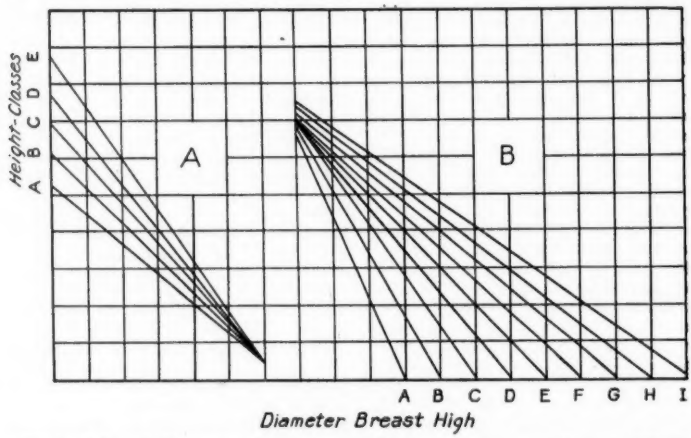

FIG. 3.—Failure of all taper curves in the same height class to converge upon the mean of the class

ing of lines in the upper part of the graph always occurs. Theoretically the result should look something like Figure 3 B, but owing to miscellaneous errors and differences in form toward the tree tips, instead of a mere failure of the lines to converge on the mean height value of the class as shown, there is a tremendous tangle of crossing lines, for there may easily be 20 inch classes in a single height class. When this is straightened out graphically and each curve forced to end at the mean value of the height class, it results in a much wider spread of values toward the top than there should be. The second curving thus straightens out the crisscrossing, but leaves the total spread of the lines about the same; the spacing is made even, but abnormally wide, so that small trees are forced to take on abnormally slight taper toward the top and big trees are made to show a great taper. The effect extends to a certain degree all the way down to breast height and tends to make the diameters of small trees (short for their height class) run small, and large trees (tall for their height class) run high. All this tends to make trees in extreme size classes show a form they do not actually possess.

In the next curving (fig. 2, C) values of trees in the same diameter class but in different height classes are combined. On every height line above the ground, values will run low in the short trees and high in tall, which merely shifts the tilt of the curves, a matter which is absolutely invisible when all are tilted equally or even harmonically. So this error passes on through to the end. Thus incorrect values caused by wrong spacing for any reason whatsoever of lines in Figure 2 A, tend to persist, as actually occurred in one instance of lodgepole pine taper curves.

The space between the lines is greater in the 70-foot class than in any other in the finished taper curve. This could be avoided to a certain degree by harmonizing the curves on a different basis to eliminate the inefficient third curve. Several alternative methods investigated by the writer, however, while more sound theoretically on account of the use of almost straight line curves throughout, proved practically as unsatisfactory in actual use and involved a great deal more labor than the system of harmonization outlined by Barrows.

The only conclusion possible from this study of Barrows's taper curve construction is that by it are readily obtained harmonized values that change

smoothly from class to class. The system, however, can not claim a great degree of accuracy. In fact, it tends to sacrifice accuracy to harmony. To work best, not only a large basis of individual measurements is needed, but they must be well distributed through many diameter and height classes so that the resulting curves may be long and their trend be clearly shown, minimizing the ever present danger of tilting the curves into incorrect positions.

The object of this criticism of the method of preparing taper curves is not to throw doubt upon the accuracy of the volume tables prepared in accordance with this system (which have proven fairly satisfactory) but to show that it is not by any means perfect and that equal accuracy may be obtained by simpler means.

FRUSTUM FORM FACTORS—BRUCE'S METHOD

One obvious way of getting around the difficulties of Barrows's method is to set a standard form of tree and compare all others with it. This is the essence of Bruce's frustum form factor idea (*4*).

The difference between the volume of a tree and the volume of a frustum of a cone having the same top diameter and the same d. b. h. ought to vary slowly and consistently with the changes of diameter, height, and form. Sudden changes are inconceivable where average trees are concerned. The frustum form factor method of volume table construction has been employed by Bruce and has proven most excellent indeed. It is easy, quick, and, as demonstrated by Bruce and others, is surprisingly accurate (*5*, *7*, *10*). It has the disadvantage, however, of what may be termed inflexibility. The final results come in one step from the basic data, and if there are any other results desired they must be worked up anew from the original measurements.

If a volume table is desired running to a 6-inch top limit, the volume of each tree to that limit must be figured and compared with the corresponding frustum. The frustum form factors must be averaged, and the computation for volume be made from them. If now a new table is desired showing volume to a 7-inch limit, the whole process must be repeated. With taper curves, the preparation of new tables is a matter of minutes. Furthermore, the taper curve system is the only one applicable to linear products, ties, props, etc.

Bruce's frustum form factor is an empirical sort of figure bearing little relation to other usually accepted tree form constants, as form factor, form quotient, form exponent. One reason is that diameter breast high outside of bark is made one of the points through which the frustum surface passes, so that the frustum form factor will vary with bark thickness, if all other factors as height, diameter, and form remain constant. Thus it is not a measure of form in the sense that some other factors are.

The frustum form factor values also will vary with the top cutting limit used, because the lower part of a tree has more conical taper and the frustum of a tree cut to a 10-inch limit will fit much more closely to the frustum of a cone than when the top limit is 6 inches, well in the top of the tree. It is possible for two tree frustums of different form and equal top and basal diameters to have the same volumes, and hence the same frustum form factors. This factor is thus an expression of volume relations rather than form relations. It is a very useful empirical figure, and the basic idea is sound. Nevertheless it fails to fill the place occupied by the taper curves. It is still worth while to discover, if possible, improved methods of curve construction.

MATHEMATICAL EXPRESSION OF TREE FORM

A simple mathematical expression of form, and a generalized equation of tree curves has been sought by European foresters for many years, but none has proven entirely satisfactory (*8*). There have been no attempts of this kind in America except the recent modification of the Höjer formula, worked out by Behre (*3*) for western yellow pine in Idaho, which is of too recent introduction to have proved its general usefulness as yet. The discovery of a simple general curve equation of this kind would go far in solving tree mensuration problems. In the search for such an equation, however, certain facts have been discovered which pave the way for a much simpler method of expressing tree form through taper curves.

PROPOSED SUBORDINATE FORM QUOTIENT METHOD

Tor Jonson, according to Claughton-Wallin, has proved that the taper of the trees of the same form class (form quotient) is independent of height with certain north European conifers. (The

fact that the taper is the same for trees of all diameters within the same height and form class had already been proved by Maass, Schiffel, and others.) Whether Jonson's dictum is strictly true or not is of little moment. It is sufficient to say that by application of this hypothesis he has developed a wonderfully accurate system of timber estimating in Sweden. If accurate enough for European conditions, it should be ample for our needs.

Accepting Jonson's statement, therefore, that taper of trees of the same form quotient is the same from the top to bottom, we have only to gather all trees of the same form quotient together and determine the diameter at regular intervals up the stem in each class. base of the tree is considered to be at breast height, and the middle diameter is at a point halfway between breast height and the tip of the tree.

Given the usual series of taper measurements, as collected in the field, the method of curve construction is not difficult. The different steps are illustrated by actual cases taken from the preparation of curves for Douglas fir in southwestern Idaho, which have been built by this method.

These taper curves were built from a slender basis of trees as an experiment to see how the new method would handle a difficult case. The basis was 1,123 trees scattered from the 12 inch–60 foot class to the 48 inch–150 foot class, a total of 136

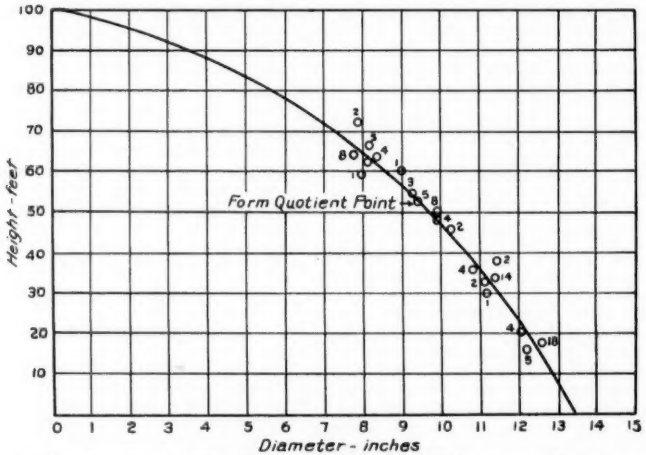

FIG. 4.—Crude taper curve for 16 inch–100 foot class Douglas fir. Numbers at points indicate number of measurements averaged

Since trees of various heights are thrown together, the points of measurement must be at equal fractions of the tree height; and since various diameters are thrown together, the diameter at any point must be expressed in terms of diameter at the base of the tree (or some other fixed point). These figures, expressing diameter at various fractions of total tree height in terms of basal diameter, are very similar to the form quotient, which is this figure in the special case when the upper diameter is taken at half the height. Diameters at other points expressed in terms of basal diameter may with propriety be designated as subordinate form quotients. It must be remembered that here we are dealing all along with *absolute* form quotients in which the different individual diameter-height classes being involved, or an average of only about 8 trees to a class. The largest single-size group—the 16 inch–90 foot class—contained only 35 trees; and 35 classes were represented only by single trees. It is obvious that a difficult test was imposed. It must be borne in mind also that the exact figures and form relationships found are not to be considered as fundamental and must not be used as the foundation of any generalized concepts of tree form—even of Douglas fir, for there are, as a matter of fact, a number of fundamental details that appear unsound. This work is to be considered only for what it is—an attempt to use a new method in building up a practical set of taper curves.

The sheets carrying the original data gathered in the field are sorted in the usual way into diameter and height classes. The diameters are then averaged and taper curves are drawn for each height class, based on diameters inside of the bark (fig. 4). Inside diameters are almost never taken at breast height. Accordingly, the curve is simply brought down from the first measurement to the base line of the graph by eye. The stump diameters should not be plotted, and no stump flare or basal swelling be allowed for, as it will tend to cause later difficulties. It is indeed much better to leave out the actual diameter inside of the bark at breast height, even if the figure is available, as on large trees it may be affected by stump swelling and introduce error into the curves at this time.

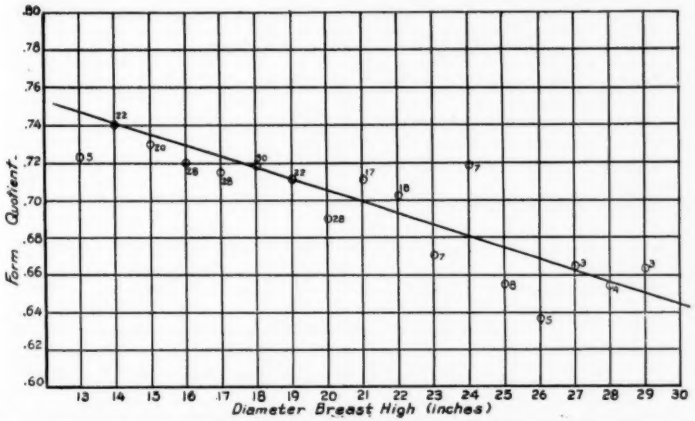

FIG. 5.—Hundred-foot class Douglas fir, showing method of smoothing irregular form-quotient values Numbers at points indicate number of trees as basis

Later it will be easy to take care of any peculiarities in d. b. h. measurements due to any cause. It is not at all necessary that the average diameter in any group should fall at the even-inch class or that the average height should fall upon the mean height of the class. After the rough diameter-inside-bark taper curve is drawn, the diameter at a point one-half way between breast height and the tip of the tree is found and then divided by d. b. h. inside bark as read from the graph. This gives the assumed absolute form quotient. After form quotients for all the size classes have been computed the values are evened off by curves.

The propriety of assigning to each size class its appropriate form quotient which shall be in harmony with that of neighboring size classes, is open to a certain amount of scientific criticism. In Europe, form is generally held to vary with the density of the stand and to vary almost as widely in a single size class as in a whole stand. It therefore becomes most proper to assign a single form quotient to the whole stand on the basis of density. Possibly we would do well enough by simply throwing all size classes together and taking a single average form quotient. In the work done by the writer, however, there is a fairly regular trend of form-quotient values according to size, the quotients falling as diameter increases (in Douglas fir) and increasing with height. Possibly this is due in part to a rough correlation of size with density in many of our unmanaged forests; but, whatever the cause may be, the result is quite apparent, and consequently the form quotients of the various size classes have been harmonized by curves.

The values for each height class may first be conveniently smoothed separately, as the form quotient tends to change very slowly within the same height class with the species studied by the author. (See fig. 5 for the 100-foot class, South Idaho Douglas fir.) There are also many diameters in each height class, which gives much longer curves than would be obtained if an attempt were made to draw curves for each diameter class separately. All of these curves should then be plotted upon a single sheet so that the relations between height classes may be judged, and any necessary adjustments made, for it is obvious that values should not run

irregularly from height class to height class. In all the work done by the author little adjustment of this kind has been necessary.

From these final curves the true absolute form quotient for each size class may be read. The next step is to select a number of the original taper curves which have a good basis in number of trees and yet show a wide variation in form quotients. After selecting 20 or 30 of these, the distance between breast height and the tip of the tree should be divided into 10 equal parts (fig. 6). The diameter of each one of these points up the tree is then read off and put down on paper. After this is done, each of these diameters is divided by the d. b. h. inside bark of the tree from which they were taken, this being done very rapidly and with ample accuracy by slide rule. In this way a series of subordinate form quotients are obtained, showing the diameter at 10 points equidistant up the tree in percentage of diameter breast high.

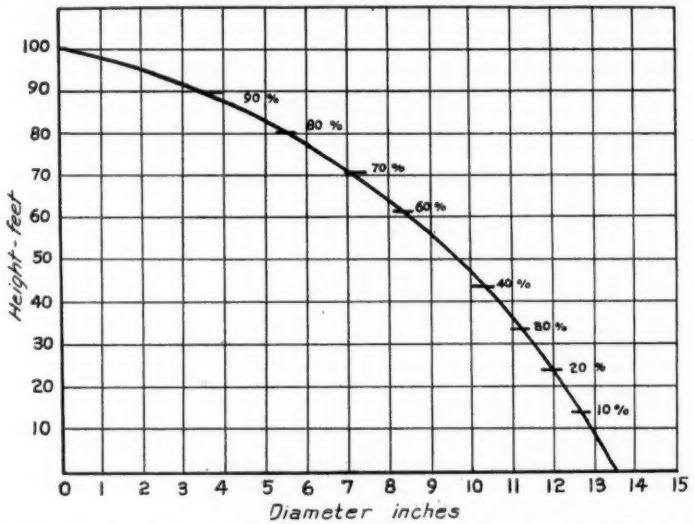

FIG. 6.—Diameter inside bark curve subdivided to determine subordinate form quotients for 16 inch-100 foot class Douglas fir

In order to even off these values a series of curves should be made, with the form quotient as the abscissa and the subordinate percentages or form quotients the ordinate. All the values which have been computed should be plotted on a single graph according to the appropriate form quotient of the tree, as shown in Figure 7. In the example of Douglas fir, here used, they fall into very good lines and require little study in order to draw the proper curves. The curve at 0.5 of the way up the tree must be a straight line because that is the form quotient line. The lines representing the diameter percentage at 40, 30, 20, and 10 per cent of the height of the tree also apparently fall in straight lines, which when extended meet at ordinate value 1.0 and abscissa value 1.0. At 60, 70, 80, and 90 per cent of the tree height they are flat smooth curves.

After drawing these curves it is possible to read off the proper subordinate form quotients for any diameter and height class after reading the proper form quotient from the curves already prepared (as in fig. 5 for the 100-foot class). It is a simple thing then to prepare a taper table if the proper base diameter is known for each d. b. h. class of trees. This can easily be ascertained by plotting the d. b. h. inside the bark from the curves first drawn against the d. b. h. outside the bark for each diameter class (fig. 8). Variations can easily be smoothed out by simple curving.

Now, having the correct diameter inside the bark, the correct form quotient, and the correct subordinate form quotients all the way up the tree, it is a simple matter to draw smooth and correct taper curves by applying the

appropriate percentage to the proper diameter inside the bark (fig. 9). To anybody familiar with curves of similar form made by the conventional system, a striking difference will be noted in the upper part of the tree, where all the curves converge into one. A wide spread is the rule in the curves made by the usual system. In effect, this harmonize the whole curves themselves by the graphic methods employed by Barrows. The results are, furthermore, very much more dependable. This method also obviates any necessity of working out mathematically the equation of these curves.

It is interesting to compare the taper found by the method here used for

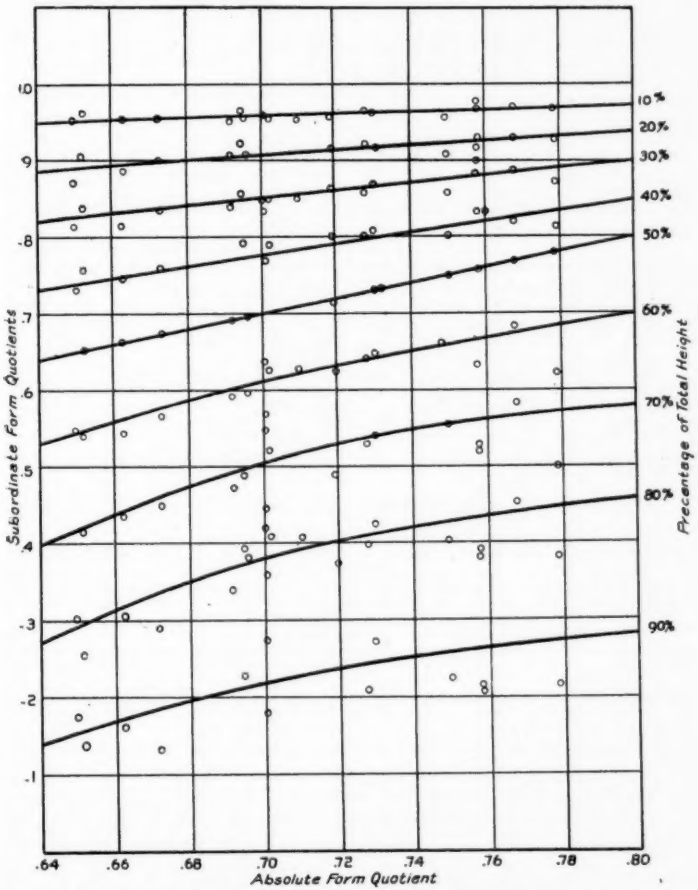

FIG. 7.—Subordinate form quotients at ten equal intervals from the base of the tree to the top for Douglas fir trees having form quotients from 0.64 to 0.80

method gives the form or taper curve of all trees having the same form quotient, and each size class of trees is assigned its tree form simply by working the form quotient into a regular, orderly sequence. It is obviously much easier to bring these simple figures into order than to arrange, rearrange, and

Douglas fir and the taper found by Behre for western yellow pine, using his modification of Höjer's equation. The difference is very slight. Taking Behre's form class 70 and comparing it with the values for form quotient .700 in Table I, which is based on the most complete data, the following results are obtained.

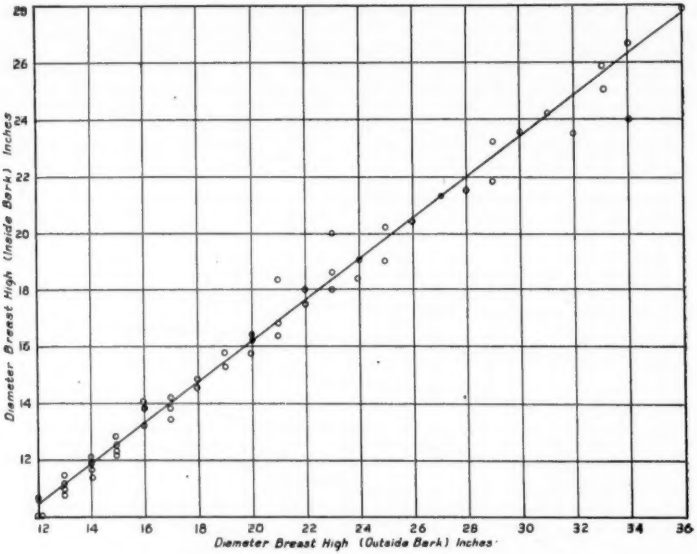

FIG. 8.—Relation of d. b. h. outside of bark to d. b. h. inside of bark

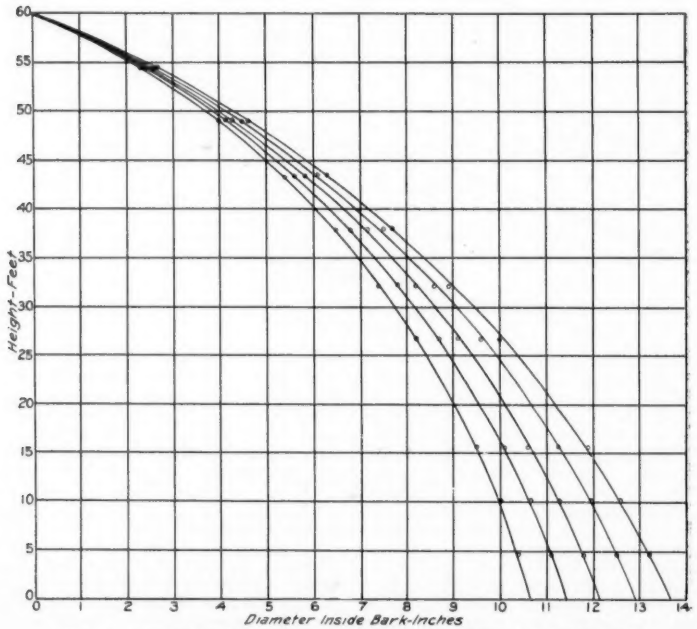

FIG. 9.—Douglas fir 60-foot class taper curves (12 to 16 inches d. b. h. inside bark)

TABLE I.—*Comparison of taper for Behre's western yellow pine form class with the taper for Douglas fir, form quotient .700*

Percentage of length from tip to breast height	Percentage of d. b. h. (inside bark)		Percentage of length from tip to breast height	Percentage of d. b. h. (inside bark)	
	Western yellow pine [a]	Douglas fir [b]		Western yellow pine [a]	Douglas fir [b]
90	95.5	96.0	40	60.9	61.2
80	90.3	90.6	30	50.1	50.5
70	84.5	85.0	20	36.9	37.8
60	77.7	77.5	10	20.6	21.5
50	70.0	70.0			

[a] Behre. [b] Baker.

TAPER CURVES BASED ON THE PARABOLOID FORMULA

The system of curve construction just described was evolved because a still simpler system failed to work on Douglas fir, although it gave excellent results with both lodgepole pine and aspen. This involves the assumption that the taper curve follows the generalized formula for a paraboloid: $Y=px^n$, or as it is more often written in forestry literature, $Y^2=px^r$. In this equation Y=diameter, x=distance from the top of the tree, and p and r are constants. This formula gives a series of parabolic curves varying in shape with the value of r, and in steepness with the values of p.

The first question that naturally arises is, how much risk of introducing error we take by the use of this hypothesis. Judging from Graves's "Mensuration," (9) it is used widely in all Europe, and exists in an implied or approximate form in many formulas for determining the volume of trees. Table II is presented to show the comparison of the theoretical form with the actual average form in the case of the 60-foot height class in lodgepole pine. The curve $Y^2=px^r$ was based upon d. b. h. and d. h/2 in this work. Column A gives the actual average values (unharmonized by curves) in each class, column B the theoretical values. It is obvious that neither is an absolute value; there is a probable error in each. This has been figured for the actual values and it runs very close to ± 0.1 inch, except in the 14-inch class, where it is nearer ± 0.2 inch. The probable errors of the computed values in columns B are of approximately equal magnitude.

It is very evident that the error in assuming the trees to be paraboloids lies well within the probable error of ± 0.1. Hence it is obvious that the form of lodgepole pine is virtually a paraboloid, at least in the 60-foot height class. Tests similar to that shown in the above table were made in a variety of diameter and height classes where a large number of tree measurements were available and the results were equally conclusive in every case. Accordingly, it was assumed that the

TABLE II.—*Comparison of theoretical form with the actual average form for 60-foot height class lodgepole pine*

D.b.h. (ins.)	Diameters at specified heights above stump (inches)											
	8		16		24		32		40		48	
	A	B	A	B	A	B	A	B	A	B	A	B
10	9.6	9.5	8.9	8.8	8.2	8.0	7.2	7.0	5.9	5.9	4.3	4.5
11	10.5	10.5	9.6	9.7	8.9	8.8	7.7	7.8	6.5	6.5	4.4	5.0
12	11.4	11.4	10.5	10.4	9.3	9.3	8.1	8.1	6.6	6.7	5.1	5.0
13	12.2	12.3	11.2	11.1	9.9	9.9	8.5	8.5	6.9	6.9	4.6	5.0
14	13.0	13.2	12.2	11.7	10.4	10.3	8.8	8.6	6.9	6.8	4.8	4.8

A=Actual average values, unharmonized by curves. B=Theoretical values.

same fact applied to all classes, and that any failures to agree were due to insufficient numbers of trees as a basis of computation. Curves were constructed upon the hypothesis. It may be noted in passing that these curves conform very closely to lodgepole pine taper curves already published (*11*).

In order to take advantage of this short-cut method it is only necessary to discover whether the taper curves in the size classes having the best basis in trees conform to the theoretical paraboloid curve. If they do so conform, the short method will suffice. If they do not conform, the method described before can be used. The methods of compilation start the same in either case. The original sheets are thrown into diameter and height classes as usual, the measurements inside bark are averaged, and separate rough taper curves are constructed for each diameter and height class. The form quotients are then computed, and the values smoothed by curves, as in Figure 6. Then, choosing several size classes where the basis in trees is heavy, the general correspondence between the theoretical curve and the actual curve should be noted. If it is close, the general similarity of all size classes to the paraboloid can be assumed. Then if FQ=form quotient, $r=\frac{-\log FQ}{0.15}$

r being the exponent in the parabolic formula $Y^2=px^r$.

The value of r always falls near 1. Then if x equals the distance from breast height to the top of the tree and Y = diameter breast high inside bark, $Y^2 = px^r$, from which p can be ascertained. Then by use of this same equation, by introducing different values for x, the diameter at various heights can be readily ascertained.

The process sounds complicated, but can be done rapidly when once mastered, especially with the aid of an alignment chart. Such a chart is illustrated in Figure 10 (*6*). It may be mounted on a drawing board and arranged with a strip of celluloid bearing a straight line pivoted with a thumb tack moving on the FQ–R line, and a thread fastened to a pin moving on the P line (fig. 10).

To solve the equation by this chart, take any diameter and height class—say the 60-foot height class—look up the form quotient for that class and pivot a line on the celluloid strip at the appropriate value. Make this line pass through the height of the tree minus 4½ feet (the distance from the tip of the tree to the "base" at breast height) on the H line. Then take the pin and thread and stick the pin in the value of diameter breast high inside bark for the particular class you are dealing with. Make the thread intersect the line on the celluloid strip on the unlettered and ungraduated line and stretch on to intersect a certain value of p, which should be marked. Then reverse the process. Stick the pin at the marked value of p. To find the diameter of the given tree 10 feet from the tip, pivot the celluloid line till it cuts 10 on the line H. Then stretch the thread from p across the intersection of the celluloid line and the plain line, until it intersects a value on line D, which is the diameter 10 feet from the tip of the tree. The method is rapid.

The advantage of this method, as well as the one first outlined, over the older method lies in their ability to iron out errors (especially those due to failure of the data in any diameter and height class), and to average up to the middle of the class, while the results are expressed in the same useful taper curves. Their advantage over the system of frustum form factors lies in the fact that they have the same ability to get accuracy from scant data and are only slightly more laborious, while the results are expressed in taper curves instead of board feet. The wide usefulness of taper curves in all kinds of volume computation, yield, etc., is too well known to need enlarging upon. The last method is also useful, for if trees are proven paraboloids, a very simple relation exists between form quotients and the regular conventional form factors, by the use of which total cubic contents can be very easily computed.

CONCLUSION

The whole subject of tree form needs deeper study so that the fundamental laws may be learned, which will lead to further simplification of methods in volume table construction. This study represents only the development of a simple but nevertheless empirical method based upon what is known at present of tree form, i.e., that trees of a given species having the same form quotients have the same form from top to bottom (excluding basal flare), and the very safe hypothesis that form (as expressed by the form quotient) varies regularly with changes in diameter and height.

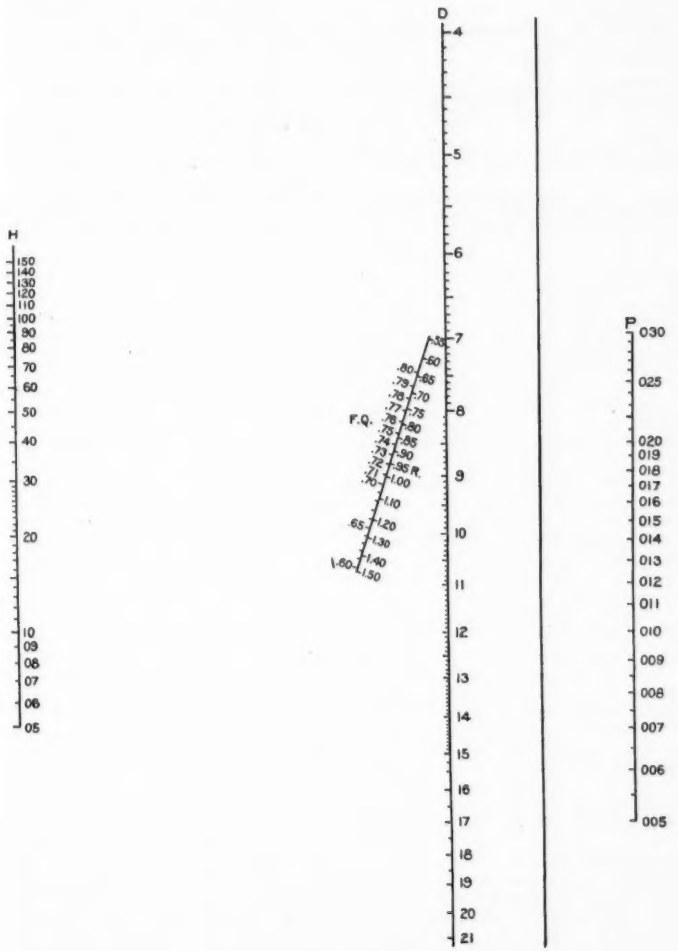

FIG. 10.—Alignment chart for solution of equation of a parabola

$D^2 = P.H^r$
D = Diameter of point H feet from top of tree.
H = Distance from top of tree to point where D is taken.
P = Parometer. Constant in trees of same size and form.
R = Exponent. Constant in trees of same form.
FQ = Form quotient D of point halfway between $B.H.$ and top ÷ D B H. Constant in trees of same form.

LITERATURE CITED

(1) BARROWS, W. B.
1915. THE CONSTRUCTION OF A SET OF TAPER CURVES. Proc. Soc. Amer. Foresters 10: 32–40, illus.

(2) ——
1915. READING AND REPLOTTING CURVES BY THE STRIP METHOD. Proc. Soc. Amer. Foresters 10: 65–67, illus.

(3) BEHRE, C. E.
1923. PRELIMINARY NOTES ON STUDIES OF TREE FORM. Jour. Forestry 21: 507–511.

(4) BRUCE, D.
1912. A NEW METHOD OF CONSTRUCTING VOLUME TABLES. Forestry Quart. 10: 215–221.

(5) ——
1913. THE USE OF FRUSTUM FORM FACTORS IN CONSTRUCTING VOLUME TABLES. Proc. Soc. Amer. Foresters 8: 278–288.

(6) BRUCE, D.
1921. THE ALINEMENT CHART METHOD OF PREPARING TREE VOLUME TABLES. Univ. Calif. Pub. Agr. Sci. 4: 233–245, illus.

(7) ——
1921. PRELIMINARY VOLUME TABLES FOR SECOND-GROWTH REDWOOD. Calif. Agr. Exp. Sta. Bul. 334, p. 235–237.

(8) CLAUGHTON-WALLIN, H.
1918. THE ABSOLUTE FORM QUOTIENT. Jour. Forestry 16: 523–534.

(9) GRAVES, H. S.
1906. FOREST MENSURATION. 458 p., illus. New York. (Reprinted, 1910.)

(10) KORSTIAN, C. F.
1915. THE USE OF FRUSTUM FORM FACTORS IN CONSTRUCTING VOLUME TABLES FOR WESTERN YELLOW PINE IN THE SOUTHWEST. Proc. Soc. Amer. Foresters 10: 301–314, illus.

(11) MASON, D. T.
1915. UTILIZATION AND MANAGEMENT OF LODGEPOLE PINE IN THE ROCKY MOUNTAINS. U. S Dept. Agr. Bul. 234, 54 p., illus.

PSILOCYBE AS A FERMENTING AGENT IN ORGANIC DÉBRIS [1]

By CHARLES THOM, *Microbiological Laboratory, Bureau of Chemistry, United States Department of Agriculture,* and ELBERT C. LATHROP, *of Samuel P. Sadtler & Son (Inc.), Philadelphia, Pa.*

INTRODUCTION

As it comes from the sugar mill, the ground cane, or bagasse, consists of fibrous tissue and crushed parenchyma, enmeshing some of the protein, gums, and coloring substances and a trace of the sugar of the cane plant. The mass averages about 50 per cent moisture, but this moisture is principally derived from water sprayed on during the grinding process, instead of natural sap.

If not burned in the furnaces, enormous masses of bagasse accumulate at the factory. During the winter of 1924, in connection with a study of the causes of spontaneous combustion, in which The Celotex Co. coöperated, we were able to examine a large quantity of this material. Masses of bagasse at that company's mill at Marrero and at several of their baling stations at sugar mills were inspected, after they had stood in piles for from two weeks to about two months. These masses illustrate clearly the principle that the composition of any particular product determines in advance the types of fermentation which will take place in it.

Bagasse heats quickly when piled according to the methods observed. The exact agents responsible for the heating process were not determined. When these heated piles were examined, certain characteristic organisms were found. In the loose piles, mucors and Trichoderma were abundant, as examined with the hand lens. When holes were dug down from the top of the pile, fruiting mucors were observable as deep as 2 to 3 feet. The temperature of the pile rose gradually, however, until it reached 62° C. between 3 and 4 feet below the surface. Bacterial examination of material taken at this level showed typical rod forms still viable, but not in great numbers. Uneven heating processes may possibly account for the survival of occasional molds which appeared in cultures from the hot materials. If any vegetative activity continued at that temperature, it was restricted to very few and very special species.

OBSERVATIONS ON BALED LOTS

In baled lots produced for a special purpose, somewhat different observations were made. Temperatures up to 60° and 62° C. were found in the center of bales deep within the larger piles, even after standing for as long as six weeks. No higher temperatures were observed, although the possibility of higher temperatures was not excluded. These piles were fairly well ventilated.

On the surface of the bales the first organism to develop was *Monilia sitophila,* which spread over the piles with great rapidity and draped them with festoons of orange fruiting masses. Even after three to four weeks, handfuls of mycelium and spores could be gathered in many places.

Bales protected from rain appeared to be so well pasteurized by the temperature attained during the heating process, which was general and so completely dried out that further activity of microorganisms was prevented. Where exposed to rain, the looser parts of the bales showed abundant fruit of mucors and Trichoderma, mostly Trichoderma, which penetrated several inches into the ends of the bale. Such molds as the Penicillia and Aspergilli were inconspicuous when apparent at all, although their presence was demonstrated by culture.

The central areas of the bales were tightly compressed and apparently furnished conditions unfavorable for the growth of the common molds. Whenever the bales had become wet and cool these central areas were penetrated by mycelia, which, as could be seen with the naked eye, followed the cleavage lines entirely through the bales as they were split

[1] Received for publication July 9, 1924; issued June, 1925.

open. The whole mass penetrated by these mycelia assumed a characteristic yellow color.

The tops of piles about 3 to 4 weeks old often showed an abundant crop of agarics, mostly a species of Psilocybe, but including occasionally Hypholomas and Coprini. Myxomycetes were seen fruiting on the sides and even on the tops of the piles, without giving evidence or suggestion of extensive participation in the fermentation observed. Cultures of the plasmodia of one very common form upon ground bagasse produced no changes comparable to those observed in the piles. Nematodes also were abundant, but their effect upon the mass was not determined.

The two conspicuous features of the fermentation were the heating process and the yellow fermentation.

Further study by the writers has been limited to the cause of the yellowing process. The preliminary survey had suggested that the mycelium belonged to some hymenomycete. Strands and streamers of hyphae were traceable up through the bales of bagasse, almost to the base of the agarics seen upon the surface.

Cultures from samples taken from many places in these piles yielded *Monilia sitophila*, Trichoderma, mucors, *Aspergillus fumigatus*, *A. terreus*, *A. niger*, *A. flavus*, Fusarium, and an occasional Penicillium, with nematodes as a common contaminant. White mycelia, producing coiled masses of microspores, were occasionally obtained, but they were not recognized at this stage of the study. Such a variety of species in culture was clearly foreshadowed by the abundance of microorganisms on the surface of the mass. The air was so full of spores that everything handled was excessively contaminated.

Tubes and flasks of the original material were prepared with the addition of various quantities of water. In certain of these tubes of bagasse a few fruits of the mushroom type were obtained. Following the technique devised by Duggar for *Agaricus campestris*, the developing caps were dissected, and the pieces were distributed in tubes of Czapek solution agar, wort agar, bagasse, and various stock media used for bacteriological work.

From tubes of wort and Czapek agar, pure cultures were obtained, from which caps identifiable as Psilocybe were eventually grown. The mycelium of this agaric proved to be white and to produce microspores in enormous numbers in masses produced by the coiling of conidia-producing branches from hyphae near the surface of the substratum. In this way whole areas became powdery with microspores in culture and reproduced extensive areas seen in the piles. Transfers from these pure cultures back to tubes of ground bagasse developed the yellow color of the original fermentation.

Cultures of this organism have fruited freely in the laboratory during February, March, April, and May at 18° to 30° C. Mycelium developed rather slowly at 37° C. without fruiting. The structure of the fruit bodies differed markedly with the nature and density of the substratum. Loose masses of bagasse in cotton-stoppered wide-mouth flasks were well overgrown with hyphae and powdery with masses of microspores, but they produced no caps. Wort agar slants were first covered with white mycelium with abundant microspores; then they occasionally produced clusters of very small caps.

On such media little buds, densely crowded along the stipes of the larger caps, appeared occasionally and produced pilei 3 to 4 mm. in diameter. Upon masses of bagasse and agar so wet as to be jellylike the mycelium remained on the surface and the pilei produced were borne upon delicate stipes almost free from surface fibrils. These pilei were thin, bell-shaped, and Psathyrella-like in appearance and texture, although the lamellae were adnexed or decurrent by a tooth as in typical forms. All sorts of monstrous forms occur upon these wet media. Globose or subglobose masses which never opened up as pilei were observed in wet agar cultures. When broken open, these often showed fully formed gills and ripe spores. On dry, closely-packed fiber, the fruits tend to be solitary and resemble fairly closely those gathered in the field.

Search of the literature of Psilocybe and related genera for the identification of this form involves many difficulties. In general, the material available is unsatisfactory because of the changes due to drying in this group and the lack of notes upon large numbers of fresh specimens. In the herbarium of the New York Botanical Garden, however, a packet of specimens collected by Earle at Auburn, Ala., was found accompanied by long-hand descriptions which tally with the writers' observations. Comparison of the spores under the microscope pointed toward the identity of the writers' material with Earle's, which had been designated a new

species by him, but had been relabeled *Psilocybe atomatoides* Peck by Murrill. That name may, therefore, be tentatively attached to the material here discussed. Since the conditions of growth make great differences in such a form as this, the following description from the material as collected and as grown in pure culture by the writers is appended:

PSILOCYBE ATOMATOIDES PECK (PROVISIONAL IDENTIFICATION)

Upon piles of bagasse and in culture, solitary to densely caespitose, especially in rich culture media. Pileus from very small to 3 cm. or even 5 cm. in diameter, convex, slightly umbonate, to subcampanulate at first, becoming nearly plane or slightly depressed in center in age, in watery media less than 10 mm. in diameter and persistently campanulate, almost Psathyrella-like; when wet hygrophanous, fawn color to avellaneous, becoming lighter shades in drier areas and in age, with surface smooth in center, becoming striately rugose at margin, and becoming concentrically rugose on drying; flesh thin white, not over 1 mm. thick. Gills broad, rounded behind, adnexed to decurrent by a tooth and with decurrent lines visible as far as 1 cm. in larger specimens, with margin white, without cystidia, becoming purple brown with the ripening of the spores. Stipe varying in length and diameter with the size of the fruit, up to 3 to 4 mm. in diameter, in the largest forms hollow or stuffed, in smaller forms solid or nearly so, from very short up to 5 to 6 cm. long in drier substrata, fibrillose scaly at base and up to the indistinct and often evanescent ring formed by remains of the universal veil, almost smooth above the ring, in wetter substrata the whole stipe indistinctly and evanescently fibrillose, often almost smooth. Spores 9 to 12 by 5.5 to 8 μ, commonly about 10 by 7 μ, purple brown (purple visible under microscope), unevenly elliptical or somewhat rhomboidal, apiculate at one end, with a pore or thin place in the wall at the other. Microspores borne upon branches from the mycelium which become coiled masses of oidia, 15 to 30 by about 25 μ.

As observed in Louisiana, thousands of tons of bagasse piled at widely separated mills were involved in this fermentation. During the first few weeks in these piles the mycelium of Psilocybe penetrates enormous masses of fibrous material and gives the yellow color to all areas attacked. The preliminary heating is clearly high enough to destroy infection in the center of the mass, even if initially present. The invasion by mycelium must, therefore, begin at the surface and progress inward. An organism abundant enough to insure such generalized presence over a large region and active enough to produce the wholesale results observed must be considered as one of the greatest agents of fermentation ever discovered. Further, this discovery directs attention to the possibilities of the mycelium of the agaricaeae as fermenting agents. In this particular case there was great rapidity in its spread to involve large masses of material. The mycelium could be followed through masses 2 feet or more in thickness and often it apparently continued downward through successive bales. The whole fermentation developed very rapidly. These activities were largely conducted in the denser areas of masses in which the growth of the common types of mold were reduced or excluded, apparently by lack of oxygen.

All of these observations harmonize with the known facts in the growth of wood-destroying types and the physical conditions which seem to surround the vegetative activity of the mushrooms in general. The significance of the series of observations lies in the clear demonstration of the enormous possibilities of vegetative activity by species of Psilocybe or of such better known groups as Hypholoma, Agaricus, Coprinus, or Cortinarius.

It is well known that agarics are widely present in the soil, as proved by fruiting caps regularly or occasionally found. One of the authors has collected *Agaricus rodmani* from the same spot along the sidewalk in Washington each spring and fall for nearly ten years, under circumstances indicating dependence for ability to fruit upon a particular balance of temperature and moisture. *Entoloma grayanum* Peck (determined by Peck) was collected from one spot in Connecticut each year for nine years. In the same way, numerous clusters of many species have been followed over periods of several years each. Everyone has observed the continuance of fairy-ring mushrooms in particular areas. All of these observations remind us of the existence of mycelia ramifying widely through the soil. Such mycelia are assumed to continue their vegetative activity over long periods and to penetrate into the deeper layers of the soil. The absence of the mushroom type of fruit is not evidence that the organisms are not present. In this case microspore production was abundant under conditions preventing mushroom formation.

Various species of Psilocybe are described, as from lawns, from clumps of mosses, and very generally from manure piles or richly fertilized ground. *Psilocybe atomatoides*, as represented in the herbarium of the New York Botanical Garden, has been found abundantly in connection with manure piles; hence it may be expected anywhere in richly fertilized soil. If the identification tentatively made here is correct, this species is capable of tremendous activity as a disintegrating agent acting upon vegetable remains in the soil.

CONCLUSIONS

Study of the fermentations occurring in large masses of organic débris (bagasse) led to the isolation of a species of Psilocybe capable of producing fermentation in this product. Mycelia were found to penetrate compact areas in bagasse where common molds were unable to develop. This development was extremely rapid and was accompanied by easily determinable visual changes in the fibrous mass.

The great activity shown by this Psilocybe in pure culture and in the field, considered together with the abundance of such forms in connection with decaying plant remains, suggests the need of intensive study of the habits and possibilities of the mushrooms as agents of decomposition, especially in the soil.

RELATIVE SUSCEPTIBILITY OF CITRUS VARIETIES TO ATTACK BY GLOEOSPORIUM LIMETTICOLUM (CLAUSEN) [1]

By HARRY R. FULTON

Pathologist, Office of Fruit Disease Investigations, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

The lime wither-tip disease is caused by an actively parasitic fungus (*Gloeosporium limetticolum* Clausen) which attacks in their young or tender stages the leaves, stems, flowers, and fruits of the variety of lime known variously as West Indian, Mexican, Common Florida, or Key lime. This disease and the fungus causing it must be definitely distinguished from the longer known "citrus wither tip" and the fungus to which it has been generally attributed, *Colletotrichum gloeosporioides* (Penz.). The latter seems to be in most cases a secondary invader rather than an active pathogen. Clausen [2] has called attention to morphological, cultural, and pathogenic differences in these two fungi. The writer has verified Clausen's main findings in this regard, and concurs in Clausen's view that earlier writers included in somewhat confusing fashion two very different fungi and their effects in their discussions of wither tip of Citrus.[3] This confusion is not altogether surprising in view of the variations which may occur in what is commonly regarded as *Colletotrichum gloeosporioides*,[4] but at the same time the two diseases have many points of difference in their grove manifestation, and the evidence is convincing that the lime wither-tip disease is caused by a distinct species, and not by a strain of *C. gloeosporioides* having unusual pathogenic abilities. Winston,[5] in connection with his studies of citrus tear stain, was unable to find, among numerous strains of *C. gloeosporioides* tested, any indication of active pathogenicity on very young fruits of various citrus species.

Severe losses sustained by growers of limes in southern Florida, especially on the Keys, led to an investigation of the lime wither-tip disease and means of control. Spraying with copper-containing materials, such as Bordeaux mixture or Burgundy mixture, has not proved to be entirely successful, due mainly to the fact that infection spreads very rapidly during rainy weather, especially on very tender new shoots that are just expanding or on the blossom parts or on the fruit when quite small (less than ⅜ inch in transverse diameter), thus making it difficult or impossible to apply with safety a protective spray-coating at the time when most needed. Secondary drawbacks to spraying may arise from the close and irregular spacing of the lime trees, from the rough topography of much of the land, from the relatively low value of the crop per tree, and from the necessity for special control of scale insects after using copper-containing sprays. Bordeaux mixture plus ½ to 1 per cent oil in the form of emulsion has given more satisfactory results in lime wither-tip control than straight Bordeaux mixture.

It would be very desirable to find some variety of Citrus immune to attack by *Gloeosporium limetticolum* that might be grown as a substitute crop for the West Indian lime, with due consideration of the requirements for citric acid and essential oil production and for beverage use. Accordingly, a rather comprehensive investigation was undertaken along this line, with the hope that it might serve as a basis for further work by horticulturists, plant breeders, or plant pathologists looking toward the final solution of the lime wither-tip problem through

[1] Received for publication June 23, 1924; issued June, 1925.

[2] CLAUSEN, R. E. A NEW FUNGUS CONCERNED IN WITHER TIP OF VARIETIES OF CITRUS MEDICA. Phytopathology 2: 217–234, illus. 1912.

[3] ROLFS, P. H. WITHER-TIP AND OTHER DISEASES OF CITRUS TREES AND FRUITS CAUSED BY COLLETOTRICHUM GLOEOSPORIOIDES. U. S. Dept. Agr., Bur. Plant Indus. Bul. 52, 20 p., illus. 1904.

[4] BURGER, O. F. VARIATIONS IN COLLETOTRICHUM GLOEOSPORIOIDES. Jour. Agr. Research 20: 723–736, illus. 1921.

[5] WINSTON, J. R. TEAR-STAIN OF CITRUS FRUIT. U. S. Dept. Agr. Bul. 924, 12 p., illus. 1921.

the finding of a satisfactory substitute citrus variety, to be propagated by budding, by cuttings, or from seed as might prove most desirable.

The ideal would be to find a naturally immune or very highly resistant individual or race in present plantings of the West Indian lime, which is practically always propagated from seed, and so might offer possibilities along this line. The writer has observed certain differences in incidence of the disease that might indicate individual difference in susceptibility, but he has not yet observed a tree that seemed satisfactorily resistant under very severe infection conditions. Such may possibly exist somewhere, and its discovery would mean the quick reestablishment of the lime industry on a better basis in territory invaded by the lime wither-tip disease, where general economic conditions are favorable.

NATURAL INFECTION IN GROVES

That the disease is very closely confined to the West Indian variety of lime is shown by general field observations during many seasons in various parts of Florida, where the West Indian lime seems to be universally affected but where varieties of orange, grapefruit, lemon, tangerine, mandarin, citron, and even such lime varieties as Kusaie, Woglum's Seedless, Buena Vista, Tahiti, and Persian are not affected when growing in close proximity to diseased West Indian limes. The only other variety observed to be affected under natural conditions has been the Dominican Thornless (or Spineless) lime, which supposedly originated as a sport from the West India lime.[6]

FIELD TESTS

During three seasons, 1919, 1920, and 1922, field tests were made on the March growth of various citrus varieties, species, and related genera to determine possible susceptibility to the lime wither-tip disease. These tests were made on property where the disease existed naturally on West Indian and Thornless limes. All of the tested trees were within 200 feet of such naturally infected lime trees, and yet no natural infection has been observed on them during the tests or during two subsequent seasons. The inoculum was a spore suspension, usually from freshly sporulating lesions on lime shoots, but sometimes from artificial cultures. Inoculations were made by wrapping cotton swabs lightly around the very tender shoots (usually 1 to 4 inches long, with many leaves in very susceptible stages), and covering for two days with paraffin paper. Control inoculations were made for every series on susceptible limes to determine the potency of the inoculum, and favorableness of condition, and water-blank controls were also made on the limes to determine what part of the observed infection might have resulted from spores naturally present on the plant surfaces. The indications were that these last played a minor part during ordinary dry weather, as might be expected, since the shoots chosen had very recently begun to develop, and since the Gloeosporium spores depend on dew drip or rain for their distribution.

The results are given in Table I. The only evidence of any susceptibility is shown by the West Indian lime and by Dominican Thornless lime, which is a derivative of it. The tests included a representative lot of commercial citrus varieties, as well as a considerable range of unusual citrus varieties, species, and a few related genera. Puncturing did not increase materially the percentage of susceptibility for the West Indian and the Thornless limes, indicating that the shoots selected for the tests were young enough to have practically maximum susceptibility without artificial injury.

The field evidence is thus very strong that the lime wither-tip disease is closely restricted to the West Indian types of lime.

GREENHOUSE INOCULATIONS

Potted plants, three of each variety, were cut back severely so as to induce the sprouting of a considerable number of young shoots. When these were barely starting the plants were placed in an inoculation case where the air was kept practically saturated with moisture. Spore suspensions of *G. limetticolum* were atomized over these plants 10 times during 21 days. Then the young shoots, which had attained several inches in length, but were somewhat etiolated and quite succu-

[6] "In 1892 on Shelford [probably intended for "Shawford"] Estate, Dominica, a lime tree was noticed without the usual formidable spines. Seeds from this apparent "sport" were collected and sown. Some 75% came true and a plot of spineless limes forms an interesting feature of the Dominican Botanic Garden. The plants in this plot are now bearing heavily, and the Curator reports that 80 to 90% of the seedlings raised are coming true." Agricultural News, Vol. 1, No. 3, May 24, 1902, p. 38.

TABLE I.—*Field tests by artificial inoculation for susceptibility to Gloeosporium limetticolum*

Varieties tested	Unpunctured					Punctured				
	Number of tests	Total shoots	Per cent positive	Per cent doubtful	Per cent negative	Number of tests	Total shoots	Per cent positive	Per cent doubtful	Per cent negative
LIMES										
West Indian	8	53	89	0	11	3	20	90	0	10
Dominican Thornless	6	91	86	0	14	2	9	89	0	11
Tahiti	8	81	0	0	100	1	5	0	0	100
Rangpur	5	60	0	0	100	1	3	0	0	100
LIME HYBRIDS										
Limequat	8	87	0	0	100	0				
Faustrime	4	68	0	0	100	1	3	0	0	100
CITRON										
Citron of commerce	3	14	0	0	100	0				
LEMONS										
Kenedy	4	35	0	0	100	2	13	0	0	100
Villa Franca	6	44	0	0	100	3	16	0	0	100
Lamb	6	54	0	0	100	3	17	0	0	100
Dwarf Chinese	2	17	0	0	100	0				
Sweet lemon	2	13	0	0	100	0				
GRAPEFRUIT										
Marsh	7	62	0	0	100	3	15	0	0	100
Silver cluster	2	15	0	0	100	0				
Walters	5	50	0	0	100	3	14	0	0	100
Conner's Prolific	1	6	0	0	100	2	5	0	0	100
Pernambuco	4	34	0	0	100	0				
Leonardi	5	51	0	0	100	1	8	0	0	100
Foster	2	21	0	0	100	0				
Royal	3	34	0	0	100	0				
Pink Marsh (Thompson)	1	8	0	0	100	0				
Sour grapefruit	1	17	0	0	100	0				
ORANGES										
Valencia	7	60	0	0	100	3	20	0	0	100
Pineapple	3	27	0	0	100	0				
Parson Brown	4	41	0	0	100	1	11	0	0	100
Ruby Blood	2	15	0	0	100	0				
Maltese	4	31	0	0	100	0				
Homosassa	4	40	0	0	100	2	10	0	0	100
Lue	2	16	0	0	100	0				
Washington Navel	1	14	0	0	100	0				
Mediterranean Sweet	1	11	0	0	100	0				
Seedling orange	1	14	0	0	100	0				
MANDARIN GROUP										
Tangerine	6	60	0	0	100	0				
Mandarin	1	13	0	0	100	0				
Satsuma	4	34	0	0	100	2	10	0	0	100
King	2	16	0	0	100	2	10	0	0	100
Temple	2	40	0	0	100	0				
Cleopatra	2	18	0	0	100	0				
VARIOUS HYBRIDS										
Tangelo varieties	8	95	0	0	100	3	20	0	0	100
Tangelolo, pink	1	18	0	0	100	0				
Faustrimedin	0					1	1	0	0	100
Natsumikan	4	49	0	0	100	0				
Citrangequat	1	3	0	0	100	0				
Tangor	2	20	0	0	100	0				
Siamelo	2	43	0	0	100	0				
Washington Navel × grapefruit	2	19	0	0	100	0				
VARIOUS CITRUS										
Sour orange	3	27	0	0	100	1	8	0	0	100
Bittersweet orange	2	23	0	0	100	0				
Sweet Bittersweet orange	2	24	0	0	100	0				
Myrtle Leaf orange	2	25	0	0	100	0				
Rough Lemon	5	32	0	0	100	3	16	0	0	100
Citrus mitis	4	29	0	0	100	1	4	0	0	100
RELATED GENERA										
Nagami kumquat	3	28	0	0	100	0				
Marumi kumquat	2	21	0	0	100	2	10	0	0	100
Chalcas exotica	1	7	0	0	100	0				
Severinia buxifolia	2	20	0	0	100	0				

lent, were punctured, dipped in a strong suspension of lime wither-tip spores, wrapped in wet cotton swabs, and replaced in the inoculation case for four days. Final observations were made eight days after removal from the inoculation case. Included in this test were West Indian lime, Kusaie lime, Sweet lime, Ponderosa lemon, seedling California lemon, Gold Medal grapefruit, Silver Cluster grapefruit, Pineapple orange, seedling round orange, Mandarin orange, Dancy tangerine, Sour orange, Cuban tangelo, and Mohawk orangelo.

The West Indian lime plants had all of the young shoots destroyed by wither tip during the first part of the experiment and no new growth was made. None of the other varieties was affected by the wither-tip disease during the progress of this very severe test.

In another somewhat similar test an inoculation chamber was used at an average temperature of 80° F. with the air practically saturated. Three plants of each variety were selected, all having very tender shoots with leaves just beginning to expand. These were punctured, and the inoculum, a heavy suspension of spores from lime lesions, was applied with cotton swabs. Further applications of spore suspensions were made with an atomizer on the second and the fifth day. On the sixth day the plants were removed from the inoculation chamber.

The West Indian lime plants developed 100 per cent infection. No infection developed on other varieties in the test, namely, Sweet lime, Rangpur lime, Kenedy lemon, Ponderosa lemon, seedling California lemon, Dancy tangerine, Mandarin orange, Pineapple orange, seedling Florida orange, Sour orange, Silver Cluster grapefruit, Gold Medal grapefruit.

Tests were undertaken to determine the susceptibility of a large number of plants grown under greenhouse conditions. Most of these were 1 to 3 years old, well branched, and furnishing flushes of growth that seemed normal. The inoculum was usually a freshly made spore suspension from an actively sporulating wither-tip lesion on the West Indian lime, but in some cases the spores were from pure cultures of *G. limetticolum*. Very young shoots were selected that had leaves young enough to develop infection if the plant was susceptible. In some tests the leaves were punctured some 50 times each. The spore suspension was applied on wet cotton, the shoot wrapped in paraffin paper, and the plant placed in a large glass-enclosed inoculation chamber over wet sand. Observations were made after 7 to 10 days. Control tests were carried on with each series to show the pathogenicity of the inoculum on West Indian lime. The results of these tests are summarized in Table II.

TABLE II.—*Greenhouse tests by artificial inoculation for susceptibility to Gloeosporium limetticolum*

Varieties tested	Unpunctured					Punctured				
	Number of tests	Total shoots	Per cent positive	Per cent doubtful	Per cent negative	Number of tests	Total shoots	Per cent positive	Per cent doubtful	Per cent negative
LIMES										
West Indian	23	74	57	11	32	39	109	93	4	3
Dominican Thornless	3	12	100	0	0	5	19	100	0	0
Persian	4	13	0	5	95	11	28	0	18	82
Kusaie	4	24	0	0	100	13	70	0	0	100
Sour Lime No. 7338 *	2	6	0	0	100	8	19	0	0	100
Sweet	3	19	0	0	100	4	26	0	4	96
Rangpur	9	41	0	2	98	19	80	0	4	96
LIME HYBRIDS										
Limequat	7	11	0	9	91	8	18	0	11	89
Faustrime	19	118	0	0	100	42	302	0	9	91
CITRONS										
Citrus medica (Susceptible strains)	14	31	0	13	87	34	87	23	21	56
Citrus medica (other strains)	17	35	0	0	100	38	84	0	20	80
Sour Citron No. 7425 *	5	9	0	22	78	6	25	0	8	92
Etrog Citron	3	10	0	0	100	9	20	0	5	95

* Serial numbers of the Office of Crop Physiology and Breeding Investigations Bureau of Plant Industry, U. S. Department of Agriculture. The writer acknowledges his indebtedness to this office for a large number of the unusual varieties included in the present investigation.

TABLE II.—*Greenhouse tests by artificial inoculation for susceptibility to Gloeosporium limetticolum*—Continued

Varieties tested	Unpunctured					Punctured				
	Number of tests	Total shoots	Per cent positive	Per cent doubtful	Per cent negative	Number of tests	Total shoots	Per cent positive	Per cent doubtful	Per cent negative
LEMONS										
Eureka	1	1	0	0	100	2	6	0	0	100
Lisbon						1	2	0	0	100
California Seedling	4	5	0	20	80	8	15	0	20	80
Villa Franca	1	1	0	0	100	3	6	0	33	67
Kenedy	1	2	0	0	100	2	8	0	0	100
Dwarf Chinese	4	9	0	11	89	11	16	0	6	94
Ponderosa	3	5	0	0	100	12	44	0	5	95
Malta Lemon	3	4	0	0	100	6	13	0	8	92
Lemon sp	4	8	0	0	100	6	13	0	34	66
GRAPEFRUIT										
Marsh	3	19	0	0	100	3	19	0	0	100
Silver Cluster	1	3	0	0	100	3	11	0	0	100
Gold Medal	1	3	0	0	100	1	5	0	0	100
Chinese Pummelo No. 11213 [a]	2	6	0	0	100	5	15	0	7	93
Sour Pomelo No. 7440 [a]	1	1	0	0	100	6	9	0	11	89
Grapefruit seedlings	7	22	0	0	100	20	74	0	9	91
ORANGES										
Valencia	2	12	0	0	100	1	6	0	0	100
Pineapple	2	4	0	0	100	4	11	0	0	100
Parson Brown	3	16	0	0	100	3	16	0	0	100
Mediterranean Sweet	2	18	0	0	100	3	14	0	0	100
Ruby Blood	3	20	0	0	100	7	18	0	0	100
China Sweet	3	7	0	0	100	5	12	0	8	92
Golden Ring	1	5	0	0	100	2	10	0	0	100
Miscellaneous	1	1	0	0	100	17	41	0	2	98
Florida Seedling	2	18	0	0	100	4	14	0	0	100
MANDARIN GROUP										
Tangerine	2	6	0	0	100	6	15	0	0	100
Mandarin	2	15	0	0	100	8	34	0	0	100
Satsuma	4	11	0	0	100	7	17	0	0	100
King						1	6	0	0	100
Temple						1	10	0	0	100
Clematine	1	5	0	0	100	3	7	0	0	100
C. nobilis	1	3	0	0	100	4	9	0	0	100
VARIOUS HYBRIDS										
Faustrimedin	3	25	0	0	100	5	38	0	5	95
Tangelo varieties	11	49	0	0	100	23	78	0	10	90
Orangelo varieties	1	5	0	0	100	3	11	0	0	100
Citrange varieties	1	7	0	0	100	4	7	0	0	100
Miscellaneous seedling hybrids	1	6	0	0	100	7	28	0	7	93
VARIOUS CITRUS										
Sour orange	2	4	0	0	100	4	17	0	0	100
Bittersweet orange	4	4	0	0	100	8	14	0	0	100
Rough lemon	2	7	0	0	100	4	21	0	0	100
Myrtle-leaved orange						1	2	0	0	100
Citrus sp. Mamis	2	2	0	0	100	3	10	0	10	90
Citrus Caibe or Moi	1	2	0	0	100	4	7	0	0	100
Limon Real						3	4	0	0	100
Citrus mitis	6	14	0	0	100	16	47	0	2	98
Citrus excelsa	9	25	0	0	100	16	40	0	5	95
Citrus hystrix	4	8	0	0	100	4	18	0	6	94
Otaheite orange	4	11	0	0	100	9	43	0	2	98
Double Flowering orange	1	2	0	0	100	2	12	0	0	100
Saigon orange	1	1	0	0	100	5	8	0	12	88
Ladoo orange	3	13	0	0	100	3	7	0	0	100
Kansu orange	3	4	0	0	100	5	14	0	0	100
Ichang lemon	5	14	0	0	100	19	53	0	15	85
RELATED GENERA										
Poncirus trifoliata	2	4	0	0	100	4	10	0	0	100
Nagami kumquat	1	1	0	0	100	8	19	0	16	84
Fortunella crassifolia	3	7	0	0	100	8	30	0	0	100
Microcitrus australis	2	13	0	0	100	8	52	0	6	94
Chaetospermum glutinosum	2	2	0	0	100	5	16	0	0	100

[a] Serial number of the Office of Crop Physiology and Breeding Investigations Bureau of Plant Industry, U. S. Department of Agriculture. The writer acknowledges his indebtedness to this office for a large number of the unusual varieties included in the present investigation.

The cases recorded above as doubtful showed decided death of tissue, but did not develop typical *Gloeosporium limetticolum* sporulation. It is very likely that such lesions were produced by saprophytic organisms that were able to invade and break down tissues under the rather extreme conditions of inoculation. In the writer's opinion these doubtful cases are in all probability negative.

In the case of the citrons, 10 strains or varieties were furnished by the Office of Crop Physiology and Breeding Investigations. Six of these lots did not show any positive evidence of infection by *G. limetticolum*, and they are averaged together in the tabulation. Four other lots did show low percentages of what seemed to be positive, although not perfectly typical infection. This was verified by culturing *G. limetticolum* from the lesions on punctured shoots, and by securing typical infection on limes from such cultures; and on this basis a positive record was made in such cases. However, the absence of any such cases on the unpunctured shoots, and the occurrence on citrus of a large proportion of doubtful lesions in which the presence of *G. limetticolum* could not be demonstrated, would lend support to the view that tender shoots of these citrons are rather subject, under the conditions of the puncture experiments, to invasion by saprophytic fungi among which *G. limetticolum* may sometimes be found. Certainly these citrons, classed as susceptible, are affected with far less frequency than the susceptible varieties of limes, and the lesions recorded as positive did not have all the typical features of lime wither tip.

Besides these somewhat questionable results from certain citrons, there is no positive susceptibility except in the group of limes, and among the varieties tested in this group the susceptibility is sharply confined to the West Indian lime and to Dominican Thornless lime.

GENERAL DISCUSSION

Clausen,[7] in his description of *G. limetticolum*, gives three host plants, *Citrus medica* var. *acida* Hook. (=*C. aurantifolia* Sw., and includes the West Indian lime which is referred to by Clausen as sour lime), *C. limetta* Risso, and *C. limonis* L. Clausen explains that the last two were artificially infected in greenhouses and that "the report of pathogenic properties on the sweet lime, *C. media* var. *limetta*, is according to C. O. Smith who is working at Whittier, Calif., with a strain of fungus supplied by the writer." The strain of Sweet lime used in the present investigation did not give positive results in 7 tests including 45 shoots, punctured and unpunctured as well as in 2 special tests of 3 plants each. Clausen reports only 2 tests of lemons (*C. limonis* L.=*C. limonia* Osb.) with *G. limetticolum*. Two trees were used in each; 1 test was negative for both trees, in the other test one tree developed "an infection of three young leaves, the other lemon, as well as the control, was not affected in any way." He further states, "the extent of parasitism on the lemon was not fully demonstrated in the experiments, but the parasitism in the one positive case was unmistakable." Clausen's inoculation tests included: 19 on sour (West Indian) lime of which 13 were positive, 4 on lemon of which 3 were negative, 8 negative on sweet orange, 8 negative on sour orange, 7 negative on grapefruit, and 4 negative on tangerine orange. Adopting the view that the sour lime, the sweet lime, and the lemon are all varieties of *C. medica* L., he states in his summary that the wither-tip fungus in his artificial infection attacked only forms and varieties of this one species.

The present investigation gives much more extensive evidence that most citrus types are immune to attack by *G. limetticolum*. It casts doubt on the reported susceptibility of sweet lime and lemon, and raises the question of whether or not certain citrons may have slight susceptibility when wounded.

It is interesting to note that commercial plantings of the West Indian lime are commonly made from seedlings. These have remarkable similarity in their general characteristics, and all seem to be highly susceptible to the wither-tip disease. A constant lookout has been kept in affected groves, and special tests of seedlings have been made for individuals immune to the disease. As yet no such individual has been found. It is possible that such individuals do exist, and the prompt discovery of one plant with high resistance or complete immunity would mean a quicker and more satisfactory solution of the wither-tip-control problem than the substitution of some other citrus variety that is immune, or the development of some new type by hybridizing.

[7] CLAUSEN, R. E. Op. cit. p. 232.

The Dominican Thornless lime seems almost as susceptible as the ordinary West Indian lime. The percentages of experimental infection were very much the same for these two varieties; the experimental lesions on the former usually developed more rapidly and extensively than on the latter; but the natural grove infection seemed somewhat less severe. This thornless type, commonly supposed to be a sport from the West Indian lime, is quite distinct from it in fruit, leaf, and stem characteristics. Seedlings from it seem to be more variable than those from the West Indian lime. Keys [5] has reported a peculiar dying and shedding of the flowers and very young pistils, due to an aborted condition of the stigmas, which might be confused with wither-tip attack.

Is susceptibility to attack by *G. limetticolum* a dominant character in inheritance? The practically universal susceptibility of West Indian lime seedlings would support a positive answer if the embryos result from true fertilization. On the other hand, the two hybrids tested that have West Indian lime parentage are nonsusceptible. Certainly the Dominican Thornless lime is very susceptible, and is the only citrus variety besides the West Indian lime out of several scores in the present tests for which there is unquestioned evidence of high susceptibility. It will be interesting and important from the standpoint of genetics to test the susceptibility of a considerable number of seedlings of the Dominican Thornless lime, as well as more hybrids of the West Indian lime.

SUMMARY AND CONCLUSIONS

The evidence here presented includes field observations on a large number of citrus varieties, species, and related genera growing near lime trees that were always severely infected with lime wither tip, as well as the results of artificial inoculations made during three seasons on wounded and on unwounded tender shoots both in groves in Florida and in a greenhouse near Washington, D. C. The West Indian lime and the Dominican Thornless lime have constantly shown a high degree of susceptibility to infection by *Gloeosporium limetticolum* of very young leaf, stem, and fruit tissue. These two varieties are probably closely related to each other. None of the other varieties of limes tested has given undoubted indication of susceptibility. Certain strains of citron (*Citrus medica* L.) have shown atypical invasion of wounded tissue by *G. limetticolum* in a comparatively small percentage of cases under greenhouse inoculation. Other varieties of limes (*C. aurantifolia* Sw.) as well as the majority of varieties of *C. medica*, have been absolutely immune to infection under the very severe conditions of the tests. This also holds true for certain first-generation hybrids having West Indian lime parentage that were subjected to test, and for representative varieties of round orange (*C. sinensis* Osb.), for grapefruit (*C. grandis* Osb.), for lemon (*C. limonia* Osb.), for kid-glove oranges (*C. nobilis* var.), and for a considerable number of miscellaneous species of Citrus and genera related to Citrus.

The close restriction of susceptibility in so far as is known practically to two very closely related seedling horticultural varieties of lime gives promise for successful substitution of other types of lime for the susceptible ones as a means of ultimately escaping losses from the disease, and points to the availability of a wide range of immune breeding stock as a basis for hybridization. Susceptibility seems not to be a dominant character in first-generation hybrids with other citrus species, but the natural seedlings of the West Indian lime, practically without exception, are highly susceptible. However, there is the possibility that a natural seedling may be found possessing immunity and having the desired characters of the West Indian lime. Such a find would possibly result in most effective and satisfactory control of the very destructive lime wither-tip disease.

[5] [KEYS, A.] ABNORMAL FLOWERS OF THE SPINELESS LIME. Rept. Agr. Dept. Dominica [Brit. West Indies] 1922–23: 23–24. 1923.

REFORESTATION BY SEED SOWING IN THE NORTHERN ROCKY MOUNTAINS [1]

By W. G. WAHLENBERG

Northern Rocky Mountain Forest Experiment Station, Forest Service, United States Department of Agriculture

INTRODUCTION

Planting denuded forest lands with nursery stock is the dependable and established way to get new forest crops started. The fact, however, that it is in many places an operation involving heavy expenditures has led the American forester to try out other methods to a considerable extent. His characteristic discontent with established practice as such, and his constant and persistent efforts to discover better ways, have led him to give not a little attention to field sowing as a possible short-cut in the artificial regeneration of forests. He considers that it is certainly successful under many conditions in nature, and he is disinclined to abandon the idea, even under very adverse conditions, because the procedure appears to be simple and close to nature's plan. When seeds germinate and the plants grow to maturity undisturbed by man there is at any rate the certainty that the root system will be normal and that the trees will not be unduly subject to windfall or similar dangers which might result from planting.

Such attempts at direct seeding in the northern Rocky Mountain region fall into two distinct classes: (1) The early extensive projects and (2) the later intensive experiments.

EXTENSIVE EXPERIMENTS

In 1910, large and very destructive fires occurred throughout the Rocky Mountain region, and the earnest desire to get new forest crops started led to extensive direct seeding projects during the following years. In all, 2,899 acres were broadcast, 10,511 acres were sown by means of corn planters, and 1,969 acres were sown in spots—a total of 15,379 acres on the national forests in the western mountains. Of this area, 53 per cent was seeded to western white pine (*Pinus monticola*), 36 per cent to western yellow pine (*P. ponderosa*), 5 per cent to Douglas fir (*Pseudotsuga taxifolia*), and 6 per cent to other species, such as lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmanni*), Norway spruce (*P. excelsa*), western larch (*Larix occidentalis*), limber pine (*Pinus flexilis*), and hardwoods. Most of these areas have been examined at least once since sowing.

Out of 343 trials, only 20 succeeded. Failures were found to be absolute in practically all cases, and all areas found to have less than 100 trees per acre were classed as failures. Broadcasting was tried generally without preparation of soil or use of poison. Of 101 attempts to reforest by this method, all failed except 9. The 153 attempts to reforest by the use of a corn planter failed likewise, with 9 exceptions. Of 89 attempts to use the seed-spot method, only 2 were successful.[2]

There is one notable success, however, on the Lolo National Forest. The ranger who made this sowing attributes the exceptional success to four things: (1) Prompt sowing after a burn; (2) seed poisoned with red lead and the area strewn with poisoned oats; (3) favorable sites; and (4) a moist season. In this case the sowing cost $4.46 per acre for labor. Other expenses brought the total cost to $6.31 per acre.

Failure is the outstanding fact in the vast majority of cases. It would be desirable, if possible, to look more closely into the reasons for the few instances of success, for the causes which made possible these exceptions might furnish some data for further observation. Unfortunately, recorded information is lacking concerning details of sowing, site, or seed conditions, some of which may have been vitally important.

[1] Received for publication June 23, 1924; issued June, 1925.

[2] In the cases both of broadcast and spot plantings there was one additional trial which appeared successful at the end of the first season but has not been examined since.

Experiments in direct seeding carried on at the Priest River branch experiment station in northern Idaho led conclusively to the opinion in 1916 that broadcast and corn-planter sowing were in general unreliable and too expensive. Since then the seeding experiments of the Forest Service in this region have been confined to sowing in prepared spots.

INTENSIVE EXPERIMENTS

In western Montana the Forest Service has had detailed seed-spot experiments under way since the spring of 1916 as a part of the planting research work at Savenac Nursery. As a preliminary step, the comparison of the adaptability of different species to seeding methods was undertaken. For this purpose it was necessary to group the species on the same site, the plan being to make later tests of the promising species on sites well adapted to each. The location selected near Haugan, Mont., is typical of the areas in need of reforestation in the region. The sites used had been severely denuded by fire in 1910, only a few snags having been left standing. Fallen trees were partly consumed by fire. The aspects are north and northwest, and the elevation ranges from 3,500 to 4,500 feet. The slopes are 35 to 65 per cent, averaging about 50 per cent, and, aside from a mixture of herbaceous plants, are being reclaimed by occasional willows (Salix), buckbrush (Ceanothus), and flowering raspberry (Rubus). The soil is a loam, clayey and stony in places.

On these areas, seed spots were installed every spring from 1916 to 1921, and during the fall in 1916 and 1918. Thirty tests consisting of 300 prepared spots each were installed during the six-year period.

A method of preparing and sowing spots which seemed to give most promise of success was adopted as standard and adhered to throughout, except in the case of sample lots of seed spots treated differently to give a check on methods. The standard method was as follows:

A surface 6 to 8 inches square was denuded of sod and herbaceous cover by means of a planting mattock. Twenty to twenty-five seeds were scattered on the resulting fresh soil surface and tamped into this soil by pressing with the flat of the mattock blade. The seeds were then hand-covered by scattering on loose soil to the desired depth, or approximately $\frac{3}{8}$ inch for western yellow pine, $\frac{1}{4}$ inch for Douglas fir and Engelmann spruce, and $\frac{1}{8}$ inch for western red cedar (*Thuja plicata*). The soil cover was not tamped.

The variations of this method included tamping the surface soil, soil sterilization against fungi by a treatment with sulphuric acid, covering with leaf litter to make spots less conspicuous to rodents and birds, and screening against these enemies.

Observations were made and recorded every 7 to 10 days during the first two growing seasons, with spring and fall survival counts the third season. The records at 10-day intervals showed germination, loss by causes, and survival. Seedlings were marked individually at the time of germination with toothpicks stained a distinctive color for each month. Subsequent notes on seedlings were recorded according to month of germination.

In 1916 western yellow pine failed because of the activity of rodents, although the survival of the seedlings, once germinated, was the highest of all species. Western red cedar failed because of low germination and drought, rodents being of no importance. The Douglas fir sowing was only a partial success, for most of the seed was damaged by rodents previous to germination, although the percentage of survival was high. Engelmann spruce, although it lost more than one-third of the plants from various causes, principally drought and cutworms, and to some extent damping-off, had survivors in three-quarters of the unprotected spots averaging more than three per spot.

In order of importance the causes of loss during 1916 were drought, insects, and fungi. The sulphuric-acid treatment did not materially lessen damping-off. The expense of using a litter cover to mask the spots against rodents did not appear to be justified, for it had but slight effect. Rodents interfered only with the large seeds. The conclusion of the season was that the work gave promise of success and justified further attempts.

In 1917 the sowings of 1916–17 were watched closely. Douglas fir proved to be not much troubled by rodents and nearly as drought resistant as the western yellow pine. Of this species, 50 per cent of the spots sown in the spring and 22 per cent of those sown in the fall of 1916 had survivors in the fall of 1917. Western larch was second with survivors in 11 per cent of fall-sown and 3 per cent of spring-sown spots. Yellow pine and Engelmann

spruce were reduced to 6 per cent and 3 per cent, respectively, in the fall series, and to zero in the spring of 1917 series. The western yellow pine proved to be very drought resistant, but both series were complete failures because of the rodents. Western white pine and red cedar were also complete failures, largely because of drought.

The conclusions of the 1917 season were similar to those of a year before but were less optimistic. The practice of seed spotting appears at best an uncertainty, much more so than planting. The results obtained certainly indicated the advisability of giving up attempts at seed spotting and of placing all attention on the surer method of planting. But in view of the greater spring of 1919 were watched. The superiority of Douglas fir appeared in each case. Western white pine was next in the fall sowings, and larch and spruce were last with but 5 per cent survival in 2-year-old spots. The spring sowings of 1919 succumbed to drought. Because of the extreme dryness of the season, drought was the foremost cause of loss.

In 1920, observations of all sowings, from the spring of 1918 to those of the spring of 1920, showed Douglas fir to be superior without exception.

In 1921, the survivals from previous series were still decreasing perceptibly in numbers. That season's sowings failed completely because of drought and cutworms.

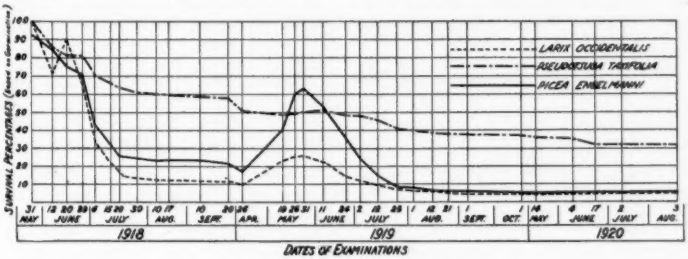

FIG. 1.—Series sown, spring of 1918

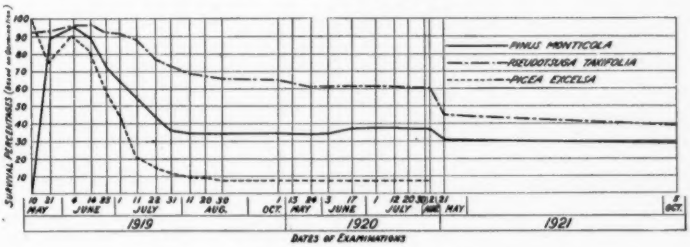

FIG. 2.—Series sown, fall of 1918

amount of work done on planting experiments in comparison with seed spots, it was thought that the work to date warranted further attempts with Douglas fir and, to some extent, with Engelmann spruce.

The season of 1918 was more favorable. The examinations made at 7 to 10 day intervals showed a loss from drought of approximately 50 per cent in Engelmann spruce and larch. The larch was the least resistant to harmful agencies, mainly drought and fungi. Douglas fir was decidedly superior to the others, showing a survival of 58 per cent at the close of the season.

During the following season the sowings of spring and fall of 1918 and

RESULTS

What has been the result as a whole of the six years of painstaking effort? What percentage of the total number of spots now contain one or more survivors? The best record is about 20 per cent for Douglas fir. Other species are not above 15 per cent in any case.

The marked superiority of Douglas fir in every sowing is evident. Although its germination as compared with its associates was less in most cases, fewer of the seedlings of this species were lost; and in every case the last examination showed Douglas fir to have more survivals per spot and a larger portion of spots with survivals.

The application of a covering of litter to mask the spots against the raids of rodents, and the use of sulphuric acid as a fungicide were ineffective. The results did not justify the expense of these operations.

In general more deaths were due to drought than to any other two causes. (Table I.) During dry summers, which have been frequent in this region of late years, the soil easily dries out completely to a greater depth than the roots of the very young seedlings have been able to penetrate. A high evaporation rate occurring at the same time soon kills them. Cutworms were next in destructiveness. Fungi were not a large factor. The remaining classes of loss, "accident," and "missing," represent numerous deaths from miscellaneous causes. Frost heaving is often an important cause of loss.

shrubs filled some of the spots and were pressed into a solid mat by snow, thus forming a mechanical barrier to germination the next spring.

Yellow pine was early abandoned in this work because of the abundance of rodents, which seek especially these large seeds. On the experimental area the western chipmunk (*Tamias quadrivitatus*) and a similar animal, Say's spermophile (*Spermophilus lateralis*), have been observed to fairly "swarm" in August and early September, while in late October one is rarely seen. Perhaps sowing should be done late, even at a sacrifice of some germination, in order to avoid them. It is likely that one of the principal reasons for the success of restocking on certain areas by broadcast seeding after the 1910 fires was the wholesale destruction of rodents by the fire.

TABLE I.—*Causes of loss of seedlings in seed spots, Haugan experiment area, Trail Gulch*

Species	Row No.	Date of sowing	Years considered	Percentage of loss from various causes						
				Fungi	Cutworms	Drought	Accident [a]	Missing	Other	Total
Picea Engelmanni	1	Apr. 26, 1918	1918–1920	7.9	15.7	64.1	1.8	7.2	3.3	100
Larix occidentalis	2	Apr. 27, 1918	1918–1920	17	9.2	59	1.5	9.3	4.0	100
Psd. taxifolia	3	Apr. 29, 1918	1918–1920	22.2	14.4	34.3	.9	10	18.2	100
Pinus monticola	4	Sept. 11, 1918	1919–1921	2.2	30.9	52.9	.7	11.8	1.5	100
Psd. taxifolia	5	Sept. 27, 1918	1919–1921	0	9.3	49.5	6.2	35.1	0	100
Larix occidentalis	6	Sept. 28, 1918	1919–1921	3.9	12.8	62	4.2	14.3	2.9	100
Picea excelsa	7	Oct. 3, 1918	1919–1920	2	22	71	1	4	0	100
Picea Engelmanni	8	Oct. 2, 1918	1919–1920	2.9	14.8	75.2	1.6	4.2	1.3	100
Do	9	Oct. 4, 1918	1919–1920	3.5	20.1	67.3	2.1	5.8	1.2	100
Psd. taxifolia	10	May 10, 1919	1919–1921	10.3	18.3	55.9	0	15.6	0	100
Picea Engelmanni	11	May 22, 1919	1919–1921	5.7	17.1	56.5	.4	20.2	.1	100
Pinus monticola	12	Sept. 11, 1919	1919–1921	2.6	25.7	44.7	5.9	21.1	0	100
Larix occidentalis	13	Sept. 12, 1919	1920–1921	11.1	14.6	24.6	22.7	27	0	100
Psd. taxifolia	14	Oct. 6, 1919	1920–1921	3	30.2	20.7	16	30.2	0	100
Picea Engelmanni	15	Oct. 7, 1919	1920–1921	6.4	32.2	27.1	13.6	20.8	0	100
Larix occidentalis	16	June 2, 1920	1920–1921	2.7	10.8	8.1	18.9	59.4	.1	100
Picea Engelmanni	17	June 3, 1920	1920–1921	1.7	22.4	38.7	12.5	24.6	.1	100
Psd. taxifolia	18	June 4, 1920	1920–1921	8.5	21.3	17	34	19.3	0	100
Picea Engelmanni	19	May 5, 1921	1921	5.2	51.9	30.8	1.1	11.1	0	100
Larix occidentalis	20	....do....	1921	4.8	44.4	29.1	.5	21.1	.1	100

[a] Among the miscellaneous causes of loss listed as accident, frost heaving seems to have been the most important.

Stones in seed spots and lying near the sowing surface presented mechanical obstacles to seedlings starting on the thin layers of soil. When the life of a seedling depends upon the deep penetration of its root before the dry summer season arrives, such obstacles are often fatal. Stones lying on the surface become very hot in the sun, attaining temperatures injurious to growing tissue; these possibly caused the death of seedlings next to them in some instances. In other cases the seed spots formed little pockets on the slope which caught rolling stones and débris. Leaves from hardwood

The tendency for western white pine seed to reserve a large part of its germination until the second season after sowing is well known. Contrary to expectations, Engelmann spruce twice exhibited such delayed germination. Both times the occurrence was in series sown in the spring, whereas fall sowings were entirely free from such hold-over germinations.

There was a complete loss before August of all germinations in screened spots sown in 1921. This is apt to happen to seed spots in this region when a dry year follows sowing. Survival data show that in most cases,

although the remaining seedlings are approaching establishment, they are still decreasing in numbers.

In this connection a statement made by a German forester since the recent war is interesting. Conditions in Germany, of course, are different from ours, and conclusions from work elsewhere can not be adopted as they stand. Nevertheless, it is well to keep in mind the development in a country older in forestry than our own. Kienitz [3] concludes that "... natural regeneration has its rightful sphere as has sowing and planting; but, in general, artificial culture has progressed far in advance and now is passing out of the sowing stage into that of the higher forest industry, namely, planting." Germany has found direct seeding successful only when a continuous moisture supply is available. The short superficial root system of first-year seedlings makes them succumb easily to drought. Planting results in a better distribution of soil moisture about the roots because of the loosened soil in the planting holes. It is the preferred method, and German experiments have shown that the cost of planting, calculated through the first three years, is less than the cost of sowing.

CONCLUSIONS

Of all the early direct-seeding projects in the northern Rocky Mountain region, only 6 per cent were successful or partially successful. Later intensive experiments with seeding in prepared spots also failed to indicate practicable methods of direct seeding for this region. Douglas fir was found to be much better adapted to success than the other local species, but all trials failed to produce a stand of survivors in sufficient numbers. Because of rodents most of the large seed sown was never allowed to germinate. Among the seedlings drought was the foremost cause of loss; cutworms were next in destructiveness, and frost heaving caused many deaths. Fungus trouble was experienced, but ordinarily was not severe. Speaking in terms of the percentage of spots with one or more survivors, about 20 per cent survival was obtained with Douglas fir under the best conditions, whereas other species were below 15 per cent in survival in all cases. Western white and western yellow pine and Engelmann spruce, important commercial timber trees of the region, are essential in reforestation and are included in the group of species making an extremely poor showing in the experiments.

It may be that direct seeding has its rightful sphere in the northern Rocky Mountain region, but if so, it has not yet been discovered. On the basis of the results here recounted, no more experiments in direct seeding are contemplated, except a test of sowing in fresh ashes after fires. A little hope for this method is cherished, but, if it succeeds, application in the region would necessarily be restricted to sites free from rodents, which possibly can be found only in the center of large, newly burned areas.

The only hope seems to lie in man's ability to reproduce the conditions which make possible nature's own direct seeding, or at least to recognize and approximate them. Nature, however, sows her seed more lavishly than the forester can afford to in his work, even to the extent of several hundred thousand large seeds and several million smaller seeds per acre, in order to secure a stand of 5,000 seedlings.[4] And she is more patient with her many delays and failures than the forester can afford to be with his.

[3] KIENITZ, M. WAS IST DENN JETZT MODE: SAAT ODER PFLANZUNG? Ztschr. Forst u. Jagdw. 51: 417–436. 1919.

[4] Based on careful counts made in the region by J. A. Larsen.

TWO IMPORTED EGG PARASITES OF THE GIPSY MOTH, ANASTATUS BIFASCIATUS FONSC. AND SCHEDIUS KUVANAE HOWARD [1]

By S. S. Crossman

Entomologist, Gipsy Moth and Brown-Tail Moth Investigations, Bureau of Entomology, United States Department of Agriculture [2]

INTRODUCTION

The State of Massachusetts, cooperating with the United States Department of Agriculture, began in 1905 to introduce into the United States foreign insect enemies of the gipsy moth (*Porthetria dispar* L.) and the brown-tail moth (*Euproctis chrysorrhoea* L.). This arrangement continued through 1911, when the Bureau of Entomology, United States Department of Agriculture, took over all of the parasite work.

Among the several foreign parasites of the gipsy moth which have been established in the United States are two species which develop within the egg of the moth. These species, known as *Anastatus bifasciatus* Fonsc. and *Schedius kuvanae* How., are now well established and both are of considerable importance as enemies of the gipsy moth in New England.

Schedius kuvanae is a native of Japan. When it was first found in gipsy-moth eggs received from Japan it was sent to L. O. Howard, who found it to be an undescribed species and genus of the Encyrtidae. *Anastatus bifasciatus*, also a member of the family Encyrtidae, has a much wider distribution, occurring in many parts of Europe, as well as in Japan.

IMPORTATION OF ANASTATUS BIFASCIATUS AND SCHEDIUS KUVANAE

The only method attempted in introducing these species was to ship the host eggs from their native lands to the United States. The masses of eggs of the gipsy moth were received packed loosely in small boxes and in cloth bags inclosed in wooden boxes. Many of the egg masses from Japan arrived wrapped separately in rice paper and packed in layers between blotting paper. Some of the shipments came in cold storage, but many were sent as ordinary express packages or by mail. From 1906 until the spring of 1910 the gipsy moth laboratory at Melrose Highlands, Mass., received many such clusters from Japan and from several countries in Europe.

When the egg masses are collected and shipped in the fall, cold storage is not necessary, since Anastatus remains in the host egg normally about 11 months. In the case of Schedius, which produces several generations during the fall, adults sometimes issue en route and parasitize some of the host eggs in the containers, thus carrying the species through to its destination. Later collections of egg clusters which have been exposed to low temperatures should be sent in cold storage, for if they are exposed to high temperatures the development of the parasites and the gipsy moth larvae is accelerated too much and may result in the issuance of the adult parasites and the hatching of the eggs.

A few gipsy-moth eggs received in 1906 from Basel, Switzerland, contained no parasites. In 1907 several small lots of egg clusters were received from Japan and Russia. No parasites were recovered from the Russian material, but one of the lots of eggs from Japan, although badly broken, showed evidence of parasitism.

[1] Received for publication Apr. 22, 1924; issued June, 1925.

[2] A. F. Burgess has been in direct charge of the parasite work of the gipsy moth laboratory, Bureau of Entomology, U. S. Department of Agriculture, since 1912. It would be difficult to name all those associated with the laboratory who have at one time or another been connected with the work. W. F. Fiske and H. S. Smith, assisted by R. Wooldridge, did much of the first investigational work with these parasites. Since then C. W. Stockwell, D. W. Jones, and J. A. Millar have greatly developed and improved the apparatus used in this work, and thus made it possible to handle large amounts of gipsy-moth eggs and parasites with a minimum amount of hand labor. The photographs illustrating this article were made by W. N. Dovener and C. E. Hood.

During the entire period L. O. Howard, Chief of the Bureau, has had supervision of the work. Many foreign entomologists have contributed to the parasite introduction project, and without their interest and aid much of the work would have been impossible.

In 1908 about 800 egg clusters came from Kief, Kishenef, and Simferopol, Russia; from those from the two places last named 470 individuals of Anastatus were recovered. A few egg clusters received from Charroux, France, showed no evidence of parasitism. During that year many attempts were made to introduce the egg parasites from Japan. Fourteen separate shipments were made, and although many dead Schedius and over 5,000 living individuals of Anastatus were received, it was not until December, 1908, that a single living Schedius was obtained. This individual was a male which died before a female was reared.

In 1909 shipments of eggs continued in larger numbers than previously, egg masses being received from Japan, Russia, Hungary, and Rumania. Nearly 10 quarts of egg masses arrived from Hungary, and from some of these the majority of the Anastatus were obtained. Anastatus was recovered from the shipments of all the countries except Rumania. In 1909 a total of 5,714 living individuals of Schedius were reared from the gipsy moth eggs which came from Japan.

In 1910 egg clusters were received from Japan, France, Germany, and Russia, but in smaller numbers than during the previous year. Living Schedius and Anastatus were recovered in small numbers from the Japanese importations, and Anastatus was present in eggs from each of the European countries from which eggs were received.

DISTRIBUTION OF A. BIFASCIATUS AND S. KUVANAE IN JAPAN AND OF A. BIFASCIATUS IN EUROPE

Schedius kuvanae and *Anastatus bifasciatus* have been reared at the gipsy moth laboratory from eggs of the gipsy moth which were collected in Japan from the towns of Akabane, Fukuoka, Funakimura, Nishigahara, and Tokyo.

Anastatus bifasciatus has been recovered from its host's eggs received from the following places in Europe: Crimea, Schiriya, Kief, and Kishenef, Russia; Lippa (Temes), Huszt (Maramoras), Dorgas (Temes), and Sistarobecz (Temes), Hungary;[3] Schlesien, Germany, and Nantes, France.

In 1922 and 1923 the writer examined eggs of the gipsy moth in France, Spain, Italy, Sicily, Germany, and Hungary. Anastatus was found in small numbers in eggs at Hyères, (Var), France, Madrid, Spain, Dahlem, Germany, and Caltagirone, Sicily.

The examination of the eggs of the gipsy moth in the field and data obtained from examinations at the gipsy moth laboratory at Melrose Highlands, Mass., show that Anastatus is a widely distributed species, but that Schedius is present in Japan only. Both species in their native lands are locally distributed and many of the egg clusters, collected from different locations, have been received at Melrose Highlands which showed no evidence of parasitism.

VALUE OF GIPSY-MOTH EGG PARASITES IN JAPAN AND EUROPE

The data obtained from examination of large numbers of gipsy-moth eggs from Japan and Europe show that both parasites discussed in this article are of considerable value as enemies of the gipsy moth in their native countries.

It would appear from the examination of eggs received from Japan, most of which were sent by S. I. Kuwana, of the Imperial Agricultural Station at Tokyo, and from observations made by J. N. Summers, of the Bureau of Entomology, that *Schedius kuvanae* is more common in Japan than is *Anastatus bifasciatus*. The two species often were present in eggs collected in the same localities, but in no case was the percentage of parasitism by both species high under these conditions. A number of collections showed no parasitism. Other collections gave as high as 33.3 per cent parasitism by Schedius. The parasitism by Anastatus usually ran lower than that caused by Schedius, and no collections were received which showed more than 2 or 3 per cent parasitism, although examination of individual egg clusters ran as high as 15 per cent.

The parasitism of eggs of the gipsy moth in Europe is very variable. Many collections from Europe received at Melrose showed no parasitism. The parasitism of eggs collected from points where Anastatus was present ran from 1 per cent to 25 per cent. The highest percentage of parasitism was obtained from a large shipment of eggs from the southeastern part of Hungary (now in Rumania), in which some 80,000 parasites were recovered. This is evidence of the value of *Anastatus bifasciatus* in parts of Europe during the season in which the eggs were collected.

[3] These towns were in Hungary before the World War. They are now a part of Rumania, except Huszt, which is in Poland.

During the last two or three years the Service for the Study and Extinction of Forest Plagues in Spain has been utilizing this parasite in its control work against the gipsy moth by transferring Anastatus from areas where it is abundant to the areas where it is not present.

EARLY EXPERIMENTS IN REPRODUCTION TO OBTAIN SCHEDIUS KUVANAE FOR COLONIZATION

In December, 1908, the first living Schedius was reared from Japanese gipsy moth eggs at the gipsy-moth laboratory. This was a male which soon died. Early in January, 1909, a female Schedius was reared. This female reproduced parthenogenetically, and 15 male Schedius were reared in February from the eggs in which she had oviposited. An attempt to mate her with her progeny was unsuccessful and she died without further offspring. In April, 1909, 12 adult Schedius were reared from Japanese eggs and used in starting several series of reproduction experiments. One of the females died soon after the beginning of the experiment. One hundred adult Schedius were obtained through these experiments, the first generation to be developed in America. Added to these were 21 adults which issued from imported eggs. The second generation gave 643 adults, which in turn produced 1,350 Schedius in the third generation. To these Schedius of the third generation were added 1,671 adults from imported eggs. These reproduction experiments, started in April, continued throughout the year 1909. In August, after the progeny from the fourth generation had issued, a few colonies were liberated. During the fall several more colonies were liberated as the stock increased, until over 40,000 Schedius had been colonized.

The Schedius in the reproduction trays continued to increase until early in 1910, when it was estimated that at least 1,000,000 Schedius were on hand. The trays containing this material were placed in a cool cellar until March. In the spring most of the Schedius and parasitized eggs were divided into a few less than 100 colonies and the material was distributed over a considerable part of the moth-infested area of Massachusetts. The Schedius and parasitized eggs not distributed were placed in cold storage for the summer, in an attempt to carry them over so that a stock would be on hand in the fall of 1910 for starting new reproduction trays. No more Schedius were obtained from this material, however, all of which perished before the end of the summer.

DESCRIPTION AND LIFE HISTORY OF SCHEDIUS KUVANAE HOWARD

DESCRIPTION OF ADULT[4]

FEMALE.—Length, 0.99 mm.; expanse, 2.39 mm.; greatest width of fore wing, 0.43 mm. Vertex and cheeks very faintly shagreened; mesoscutum nearly smooth, shining, with minute, rather sparse punctures; mesoscutellum densely and rather coarsely shagreened, well rounded at tip; propleura very faintly shagreened, somewhat shining. General color black; mesoscutellum with a bronzy luster; trochanters, tips of femora, apical half or a little more of front and middle and hind tibiae yellowish; all tarsi lighter; antennae dark brown; dark parts of the legs more brown than black. Wings hyaline. [See fig. 1, *a*.]

MALE.—Length, 0.9 mm.; expanse, 2.28 mm.; greatest width of fore wing, 0.43 mm. Resembles female, except that the flagellum of the antenna is light brown, and except for the structural characters mentioned in the generic diagnosis.

Described from numerous male and female specimens reared September, 1908, at the gipsy moth parasite laboratory of the State of Massachusetts and the Bureau of Entomology, at Melrose Highlands, Mass., from the eggs of *Porthetria dispar* received from Tokyo, Japan, from S. I. Kuwana, Entomologist of the Imperial Agricultural Experiment Station at Nishigahara, Tokyo, after whom the species is named in partial recognition of his great services to the United States in sending parasites from Japan.

TYPE.—No. 12158, United States National Museum; Gipsy Moth Laboratory No. 1698.

OVIPOSITION AND IMMATURE STAGES

Females of Schedius deposit their eggs within the egg of the gipsy moth and if the host larva is developed, as is usually the case, the parasite egg is placed within the body of the caterpillar. The egg (fig. 1, *b*) has a long stalk which is attached to the host egg at the point where the egg of the gipsy moth was punctured by the female parasite. Gipsy-moth eggs which have been exposed to Schedius females in laboratory experiments often have several parasite eggs placed in them by the same or different females. The time required for oviposition varies considerably and records of from 9 to 45 minutes have been obtained. The process usually takes from 10 to 20 minutes.

Oviposition (fig. 2, *a*) often begins during the first day of adult life and extends over several weeks. In one experiment where seven fertilized fe-

[4] HOWARD, L. O. TECHNICAL RESULTS FROM THE GIPSY-MOTH PARASITE LABORATORY. I. THE PARASITES REARED OR SUPPOSED TO HAVE BEEN REARED FROM THE EGGS OF THE GIPSY MOTH. U. S. Dept. Agr., Bur. Ent. Tech. Ser. Bul. 19: 1–12, illus. 1910.

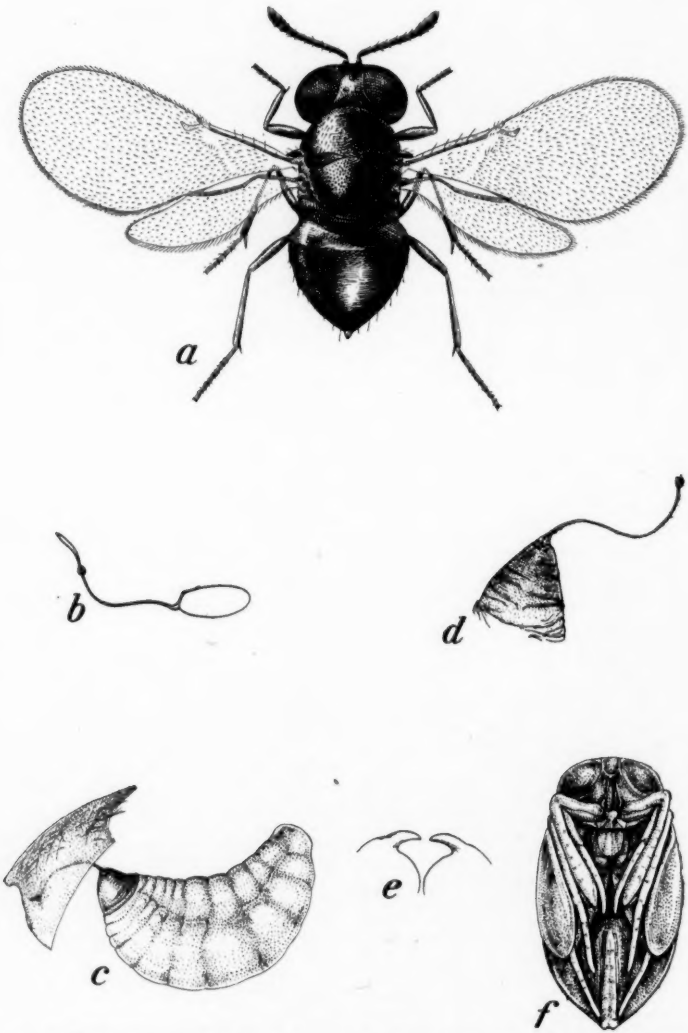

FIG. 1.—*Schedius kuvanae:* *a*, Adult female; *b*, egg; *c*, third-stage larva still retaining egg-stalk and anal shield; *d*, egg-stalk and anal shield of larva as found in host eggs of the gipsy moth from which the adult Schedius has emerged or in which the Schedius larva has been attacked by a secondary parasite; *e*, larval mandibles; *f*, pupa. All greatly enlarged. (Howard and Fiske)

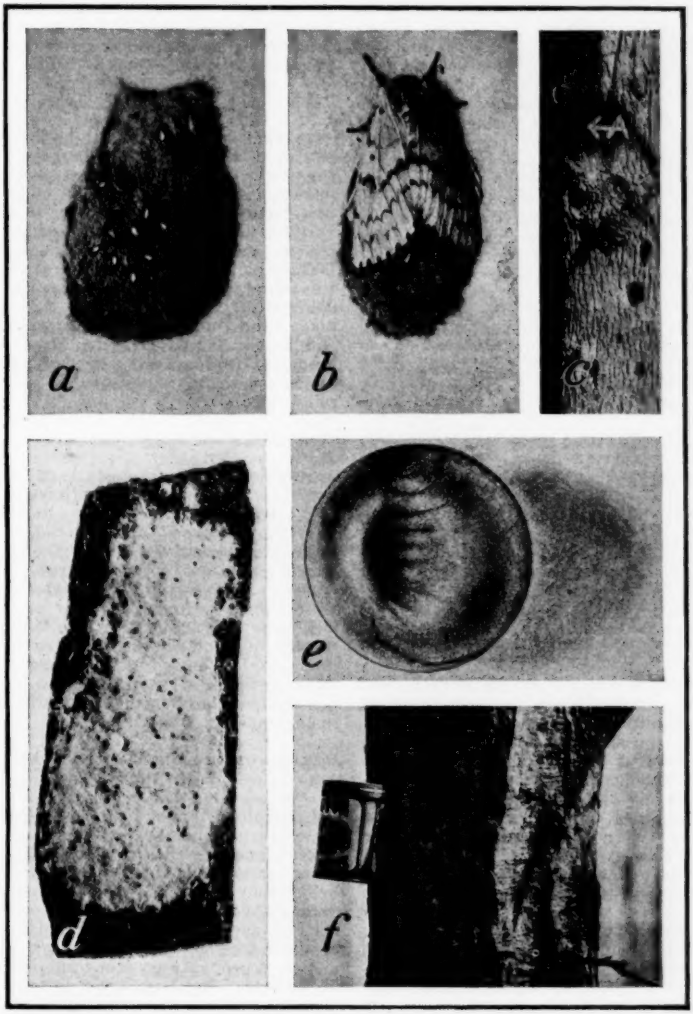

FIG. 2.—*Schedius kuvanae* and *Anastatus bifasciatus: a*, Gipsy-moth egg cluster with adult Schedius on it; *b*, female gipsy moth depositing egg cluster, with female Anastatus on cluster; *c*, Anastatus colonization mark on roadside tree; *d*, gipsy-moth egg cluster showing exit holes of Schedius; *e*, hibernating larva of Anastatus as seen within host egg (Howard and Fiske); *f*, Anastatus colonization can in position on tree trunk

male Schedius were in the presence of gipsy-moth eggs for 23 days, the resulting progeny showed that oviposition had taken place during each one of these days. The females were then transferred to another lot of gipsy-moth eggs and continued to oviposit during the following three weeks. One individual oviposited 27 days later, or 71 days after issuing. The other Schedius oviposited during a period of six weeks. Seventy per cent of the oviposition took place during the first three weeks of adult life.

In regard to the later life of Schedius within the host egg, the following is taken verbatim from Bureau of Entomology Bulletin 91 (p. 180), by L. O. Howard and W. F. Fiske: [5]

> When the egg hatches, the larva does not entirely leave the shell, but remains with its anal end thrust into it, and the stalk, which is hollow, becomes functional and acts like a lifeline attached to a submarine diver in supplying a connection with the outer air. As the larva grows the stalk increases in thickness, and the last anal segment of the larva becomes covered with a thick chitinized shield, which is unaffected by the action of strong caustic potash. There are two larval molts, and consequently three larval stages. During the entire course of both the first and second the young parasite remains quite firmly attached to its anal shield and lifeline and the cast skins are not entirely sloughed off, but are merely pushed backward. After the third ecdysis it retains this connection for a while, and grows rapidly, but about the time when it reaches maturity the connection with the shield is broken, thus proving that it is not part and parcel of the integument. It would appear rather that this shield, including a tube within the egg-stalk (which, as stated, grows in thickness after the egg itself hatches), is actually part of the integument of the first-stage larva, and that the second and third stages merely continue to use what is in effect the skin of the first larval molt.

A third-stage larva, with egg-stalk and anal shield still retained, is shown in Figure 1, *c*, the detached egg-stalk and anal shield at *d*, and larval mandibles at *e*.

The Schedius larva within the gipsy-moth egg consumes the entire embryo if it is in a new egg in which the host larva has not developed. When the Schedius egg is placed within a host egg in which the gipsy-moth larva has developed, the parasite maggot devours the entire caterpillar except the hard chitinized parts and the hair. The hair is left clinging to the inside of the host eggshell. This superficial character is used in determining that Schedius has been present in the egg under consideration.

In 16 to 17 days after the deposition of the parasite egg the Schedius larva is full grown and transforms to its pupa (fig. 1, *f*). The usual period during warm weather from oviposition to the issuance of the adult parasite (fig. 2, *d*) is 21 days. This time varies considerably with the climatic conditions. More time is required for its development during prolonged cool or wet weather and late in the fall. The first spring generation requires about six weeks for development.

FEEDING

In the breeding work at the laboratory adults of Schedius have been fed sugar sprinkled lightly on the inside of banana peeling. A solution of one-half honey and one-half water is also very satisfactory. This solution is placed on paper or blotting paper. (White blotting paper is used, since it was found that Schedius had sometimes died after feeding on this mixture placed on colored blotting paper.) Adult Schedius have been noticed apparently feeding at the punctures made by their ovipositors in gipsy-moth eggs.

LONGEVITY EXPERIMENTS

Schedius adults are quite hardy and live for many weeks when they have food and proper conditions. Records have been obtained of female Schedius living 24 days without food. The male Schedius do not live as long as the females and usually both sexes die within three or four days after issuing if food is not available. The longest records of adult life of Schedius with food are 105 days for males and 130 days for females. Many records have been obtained of Schedius adults living for five and six weeks.

NUMBER OF PROGENY AND PROPORTION OF SEXES

Laboratory experiments to determine the number of progeny from a single female Schedius have shown great variations. Many females die before they have had sufficient time to deposit the full number of eggs of which they are capable. This early mortality of many females under laboratory conditions is probably greater than occurs in the field. In laboratory experiments there probably is more superparasitism of the host eggs than is the case in the field. When more than one Schedius egg is placed in a gipsy-moth egg it is usually wasted, for very rarely does more than one Schedius develop in such an egg.

[5] HOWARD, L. O., and FISKE, W. F. THE IMPORTATION INTO THE UNITED STATES OF THE PARASITES OF THE GIPSY MOTH AND THE BROWN-TAIL MOTH: A REPORT OF PROGRESS, WITH SOME CONSIDERATION OF PREVIOUS AND CONCURRENT EFFORTS OF THIS KIND. U. S. Dept. Agr., Bur. Ent. Bul. 91: 312, illus. 1911.

The largest number of Schedius which has been recorded at the laboratory as developing from a single fertilized female is 191. In these experiments 40 pairs of fertilized Schedius were used. The records of four pairs were 183, 180, 161, and 152. The progeny of several of the other pairs numbered less than 100, and the average progeny from one pair of Schedius, 105. It is probable that under favorable conditions in the field many Schedius deposit at least 200 eggs.

Records obtained at the laboratory show that female Schedius are more abundantly produced from fertilized parents than are males. One typical set of data, concerning over 4,000 adults reared and examined, shows that 74 per cent of the issuing generation were females.

In jars at the laboratory there has been considerable in-and-in breeding. Parents and offspring and brothers and sisters have mated, and the first generation has showed no apparent weakness. In the large reproduction trays (fig. 3, *a*, *b*), in which Schedius are bred for colonization, there is considerable in-and-in breeding. After five or six generations have been produced the resulting Schedius are smaller and weaker than those of the first few generations, probably because of the continued in-and-in breeding.

PARTHENOGENESIS

Schedius reproduces parthenogenetically, the resulting offspring always being males. In laboratory experiments in which females have not been allowed to become fertilized the average number of the progeny has been about 50. This is much lower than the average number of progeny obtained in similar experiments conducted with fertilized Schedius.

SUPERPARASITISM

Gipsy-moth eggs which have been exposed to Schedius in laboratory experiments often contain more than one parasite egg. In these experiments the same female often oviposits more than once within the same host eggs, and occasionally she pierces a host egg with her ovipositor but does not insert an egg. Hundreds of thousands of gipsy-moth eggs collected in the field are examined with a binocular microscope each year, and only a very few cases have been observed where more than one Schedius has developed within an individual gipsy-moth egg.

HIBERNATION

The manner in which this parasite passes the winter was for a long time in doubt. Schedius is present late in the fall in gipsy-moth eggs and will often issue from eggs collected in December. Schedius rarely issue from egg clusters collected after winter begins and temperatures of 15° F. and lower are recorded. Examination of such eggs with a binocular microscope often shows all stages of dead Schedius within the eggs. Hundreds of thousands of gipsy-moth eggs containing all stages of living Schedius have been kept through the winter in cold storage at temperatures around 30° F. Similar lots of eggs have been kept in various types of containers, under as nearly natural conditions as possible, in cages in the laboratory yard. Such experiments have been tried during a number of years but in no case has a single adult Schedius been obtained the following spring.

Many experiments similar to those just mentioned have been conducted with adult Schedius to obtain positive records of adult hibernation. Such experiments often failed to carry Schedius through. In the next succeeding paragraphs are described the first experiments in which the proof was positive that Schedius were carried successfully through the winter as hibernating adults.

A wooden tray (10 by 10 by 4 inches) with a wooden base was prepared for the hibernating experiment. On the inner sides were tacked several small strips of felt and pieces of cotton batting. Several small pieces of such padding were folded and moistened with a solution of one-half water and one-half honey. This tray after being stocked with Schedius was placed in a Riley cage in the yard and left there until completion of the experiment the following summer, except when it was taken into the laboratory for observation.

On October 6, 1915, about 50 adult Schedius and a few gipsy-moth eggs were placed in the tray. The several observations which were made up to November 10 showed Schedius to be active, but many adults had died. On this date a few more adults were added. On November 18 some Schedius were still alive, especially on the sides of the cage close to the felt. On December 21 the temperature at the laboratory yard descended to 13° F., but on December 23 Schedius were still alive. A number were clinging to the sides of the tray

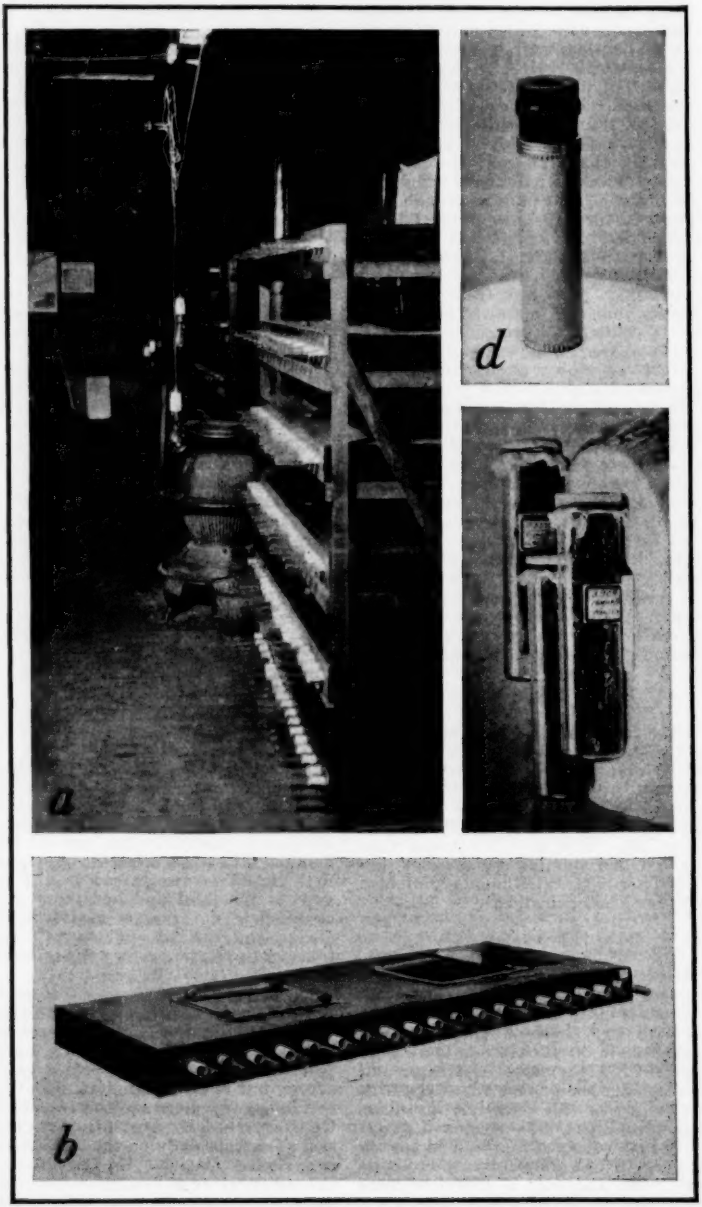

FIG 3.—*Schedius kuvanae* and its colonization: *a*, Two stacks of Schedius rearing trays; *b*, a single rearing tray; *c*, glass vials containing gipsy moth eggs from which Schedius adults were obtained for stocking rearing trays; *d*, mailing tube into which adult Schedius are transferred from the rearing trays. A removable cover in the top of the mailing tube contains a spring trapdoor which prevents the Schedius from escaping. When the tube contains 4,000 Schedius, this cover is removed and the top is covered with a piece of cotton cloth

near the felt and also near the cotton at the base of the cage; some were present in the folded food cloth, and a few were under the gipsy-moth egg masses. On January 3, 1916, all of the gipsy-moth eggs were removed. During the week of January 3 to 10 the thermograph in the yard recorded as low as 6° F. and on several days below 10°. On January 10 the Schedius were observed crowded together in little groups on the walls of the cage near the felt, and a few were in the folds of the food cloth. A few which were brought into the laboratory began to move within 15 minutes. During the week of January 9 to 16 the temperature fell to 3° F. On January 17 a few Schedius were brought into the laboratory; one of these moved in 10 minutes after being in the warm room and several became quite active within 45 minutes. Many which had dropped from the walls of the cage were dead, apparently killed by the cold. The reviving Schedius were in all cases females. There was a small amount of snow on the ground at this time but the Schedius in the cage were probably not so well protected from cold as they would have been if they had been covered with snow.

The temperature in the yard was below zero on February 14 to 16, and on the 14th the thermograph registered −10° F. The ground and cage were covered with over a foot of light snow. The cage was examined on February 16 and many dead Schedius were found on the floor. A few Schedius in the food cloth revived after being exposed for a short time in the laboratory. On March 8 several living Schedius were noted after the tray had been brought into the laboratory for a short time. On March 27, a warm spring day, several Schedius were seen to move in the cage. Again on April 11, a warm sunny day, several Schedius were seen moving about in the cage. A few nonparasitized gipsy-moth eggs were placed in the tray on this date with a small quantity of food (one-half honey and one-half water). On May 8 these eggs were removed, and on May 22 adult Schedius began issuing from them. On April 24 several Schedius were seen active in the cage. On May 2 over 20 adults were running about the cage, and three gipsy-moth egg clusters were placed in the tray. Most of the Schedius were ovipositing in the eggs which had been put in the tray on April 11. After a short time one female oviposited several times in a new egg cluster. On May 13 the second lot of gipsy-moth eggs which were placed in the tray began to hatch. The Schedius were very active and oviposited freely. On May 20 all but six of the hibernated Schedius were dead. The weather had been cool and rainy for several days. On May 27 only two Schedius were alive. On this date two of the three egg clusters which were put into the tray on May 2 were removed. On June 25 two Schedius issued from the two egg clusters removed. One hibernated Schedius was alive on June 2, and one female Schedius was still alive on June 24. When the tray was next observed a generation of Schedius had begun to issue from the single egg cluster which remained in the cage, so that it was impossible to know how long after June 24 the hibernating female had lived. The mortality of Schedius late in the fall is enormous and only a very few strong females in especially favorable hibernating quarters survive. It is probable that the females which hibernate successfully are fertilized in the fall but do not oviposit, for the first individuals found early in the spring are always large females with greatly extended abdomens. Both sexes are present in the progeny developed from these hibernating females. It is probable that certain individuals enter hibernating quarters at various times during the fall and thus lessen the chance of extermination should a sudden drop in temperature late in the fall kill all of the active individuals.

NUMBER OF GENERATIONS

The records obtained from hibernating experiments carried on at the laboratory have been substantiated by field observations. Schedius which have hibernated successfully become active on the first warm days of April and are occasionally observed ovipositing during the latter part of this month in the overwintering gipsy-moth eggs. They are scarce at this early date and it is probable that the first few seen in April have hibernated in protected spots which were warmed by the early spring sun. Only rarely do Schedius issue from eggs collected before the middle of April, and the majority do not leave their winter quarters until the last week of this month. These adults, which are always females (at least no males have been found in the spring until there has been ample time for a spring generation to develop), live three to five weeks, so that the oviposition period is prolonged over several weeks. Six weeks are required for the first spring generation to develop on the overwin-

tering gipsy-moth eggs. It follows that adults of the first spring generation begin issuing from gipsy-moth eggs about the last week of May and continue well into June, the greater number issuing during the first half of June. Both sexes are present in this and future generations, indicating that some, if not all, of the females which hibernated successfully were fertilized during the preceding fall. Many of the adults of the first spring generation oviposit in nonhatched gipsy-moth eggs. Adults of the second spring generation are found issuing from the beginning to the middle of July. Experiments have shown that adult Schedius often live five to six weeks, ample time being thus afforded for many adults of the first generation to oviposit in the new gipsy-moth eggs which are laid in July.

Adult Schedius are often seen ovipositing in gipsy-moth eggs before the entire cluster is deposited by the moth. The first fall generation issues about 21 days after oviposition, or during the first week in August. A part of the first fall generation often has issued before all of the gipsy-moth eggs have been deposited. The generations during the fall so overlap one another that they can not be definitely separated, but there is time during the average season from the middle of July until early in November for four complete generations and a partial fifth. During the warm weather from the middle of July to the middle of September there is a generation about every 21 days. The last two generations require somewhat more time in which to develop and many of the Schedius within the host eggs which would otherwise become adults of the fifth generation are killed in various stages of development by severe temperatures.

The approximate time of the appearance of each generation of Schedius is here given. The dates vary considerably during different seasons.

April 10 to May 15: Hibernated female Schedius active in the field.

May 25 to June 8: Adults of the first spring generation, both sexes, issuing from host eggs.

June 30 to July 15: Adults of the second spring generation (partial) issuing from nonhatch gipsy-moth eggs.

Week of August 5: Adults of the first fall generation issuing.

Week of August 26: Adults of the second fall generation issuing.

Week of September 16: Adults of the third fall generation issuing.

Week of October 14: Adults of the fourth fall generation issuing.

November 11 and later: Adults of the fifth fall generation (partial) issuing. Cold weather causes the death of many of this generation within the host egg.

REPRODUCTION ON GIPSY-MOTH EGGS

Schedius reproduces on freshly deposited eggs of the gipsy moth as well as on those in which the embryo is fully developed. Freshly deposited eggs have been kept for a month in cold storage at a temperature of about 30° F. and then exposed to Schedius. An examination of these eggs showed no development of the embryo, and Schedius reproduced readily on such eggs. During the major part of the breeding period of the Schedius the host eggs are well developed, and at such time Schedius acts as a parasite of the unhatched gipsy-moth larva within the host egg.

Many records have been made of the breeding of Schedius on dead gipsy-moth eggs. Some of the early work on breeding at the laboratory was greatly facilitated by using gipsy-moth eggs which had purposely been killed by being placed in hot water. In this manner the breeding was continued during the winter and spring months without interference from the hatching of gipsy-moth larvae. Gipsy-moth eggs have been held in cold storage for two years until all or practically all of them were dead, and then have been used successfully for reproducing Schedius. Some of the adult Schedius from the first spring generation oviposit successfully in gipsy-moth eggs which have failed to hatch earlier in the spring. Schedius bred from dead gipsy-moth eggs are not so strong and robust as when bred on healthy gipsy-moth eggs.

REPRODUCTION ON EGGS OTHER THAN THOSE OF THE GIPSY MOTH

Schedius has been bred successfully at the laboratory in eggs of the following: *Hemerocampa leucostigma* S. & A., *H. definita* Pack., *Callosamia promethea* Dru., *Malacosoma americana* Fab., *Hemileuca maia* Dru., *H. oliviae* Ckll., *Euproctis chrysorrhoea* L., and *Stilpnotia salicis* L. It is interesting to note that in a few cases of parasitism of a large egg like that of *H. oliviae*, several Schedius developed in an individual egg. On two occasions five, and on a number of occasions two and three, Schedius issued from a single egg. Parasitism of these species by Schedius in the field is probably of rare occurrence, and in no case have Schedius been reared from any of the eggs above

named which have been collected in the field. The fact that it is possible for Schedius to reproduce on such a variety of host eggs is important, and it may yet be found parasitizing these and other lepidopterous eggs when conditions are favorable.

SCHEDIUS AS A HYPERPARASITE ON APANTELES MELANOSCELUS RATZ

One of the parasites of the gipsy moth which have been imported from Europe is *Apanteles melanoscelus*. Among 87,000 cocoons of this species which have been collected during the last three years to be used in colonization work, 11 were found from which *Schedius kuvanae* had issued. These cocoons had been isolated in gelatin capsules, in which the Schedius were found. As a hyperparasite on *A. melanoscelus*, it often happens that more than one Schedius issues from a single cocoon; on one occasion 17 adult Schedius so issued.

DEVELOPMENT OF SCHEDIUS ON LARVAE OF ANASTATUS

Schedius developed on full-grown larvae of *Anastatus bifasciatus* in some of the gipsy-moth eggs introduced from Japan. Many attempts have been made at the laboratory to rear Schedius on gipsy-moth eggs which have been parasitized by Anastatus. It is surprising that in only one case has this resulted in producing a generation of Schedius. Many hundreds of thousands of field-collected gipsy-moth eggs have been examined with a binocular microscope in the course of the work during the last 14 years, but there is no record of Schedius issuing from an egg which previously had contained Anastatus. In a few instances Schedius and Anastatus larvae have been found within the same egg, but in such cases neither has issued.

These two parasites are not often found to be abundant in the same locality. The examination of eggs of the gipsy moth usually shows one or the other in a great majority. In a few places both species are occasionally about equally represented. It seems probable that in some areas these parasites must conflict, but it is not apparent which one is the survivor. From the habits of the two species it would seem that Anastatus would suffer in an area where Schedius is abundant. In laboratory experiments Schedius has been observed to oviposit in gipsy-moth eggs containing Anastatus, but these eggs have not developed except in very rare cases, and in those the Schedius have not issued.

LATER REPRODUCTION WORK AND APPARATUS USED TO OBTAIN SCHEDIUS KUVANAE FOR COLONIZATION

Many types of containers have been tried in the development of the present apparatus used for breeding Schedius. In the first work on reproduction, when very few Schedius were available, small glass vials (1 by 4 inches) containing a few gipsy-moth eggs were used. Later, as the Schedius became more abundant, a larger glass vial (8 by 2 inches; fig. 3, *c*) was found more satisfactory. With the increase of the parasites wooden trays (14 by 14 by 2½ inches) with glass tops and bottoms of cotton cloth were found to serve the purpose better.

In August of each year a few gipsy-moth eggs were collected at locations where the parasite was present and placed in glass tubes (8 by 2 inches) for the issuance of Schedius. The tubes were examined often during the day and all of the adult Schedius were removed and transferred to the breeding trays, in which had previously been placed a supply of masses of gipsy-moth eggs. As the breeding work increased larger trays (5 feet long, 2½ feet wide, 3 inches deep) were used. These were lined with black paper and covered with white cotton cloth, but were not satisfactory, for if the paper broke, as it often did, many adult Schedius, trying to get to the light, were caught between the paper and the cloth and died there. A very satisfactory tray has at last been developed (fig. 3, *b*), made of matched boards of half-inch cypress with corners dovetailed so as to be tight. The bottom and top are of the same material. The tray, by outside measurement, is 5 feet long, 2 feet wide, and 5 inches deep, and is painted on the inside with flat black paint. Two holes, each 12 inches square, are cut in the top, each halfway between the center and end of the tray, so that the eggs can be properly spread over the bottom and light may enter. The holes are covered with window glass. In the front of the tray are 19 circular holes, 1 inch in diameter, usually kept closed with cork stoppers.

During the latter part of August or early in September the bottoms of these trays are covered evenly with a half-inch layer of gipsy-moth eggs. The holes in the front of the trays are plugged with cork stoppers until it is necessary to draw out the Schedius. Then a few gipsy-moth eggs collected from places where Schedius are plentiful are placed in each tray. The trays

are stocked at intervals of several days, so timed that after the resulting generations begin to issue the flow will be gradual and continuous; for it would be difficult to handle so many adult Schedius should they all appear at the same time. After the trays are stocked they continue to yield Schedius for four or five generations without further care except to feed the adults and to keep the room warm. In from 21 to 25 days after the introduction of Schedius into the breeding trays a new generation of parasites issues.

In order to draw the adult Schedius from the breeding trays it is necessary to exclude the light, which is done by placing pieces of black paper over the glass in the tops. The cork stoppers are removed from the front of the trays and glass vials (4 inches by 1 inch) are substituted. The vials are held in place by means of small paper cones inserted in each hole. Electric lights are hung in front of the trays (fig. 3, *a*). As the Schedius enter the vials each vial is replaced by an empty one and an estimate is made of the Schedius in the vial withdrawn. The adult Schedius are then transferred from the vial into a mailing tube 8 by 3 inches in size. To do this, in the top of the mailing tube is placed a removable cover with a trap-door through which the open end of the glass vial containing the Schedius is inserted (fig. 3, *d*). By tapping the bottom of the inverted vial the Schedius drop into the mailing tube. When the glass vial is withdrawn the door springs back into place, preventing the Schedius, which are very active, from escaping. When the tube contains about 4,000 Schedius a slip of paper smeared with a solution of one-half honey and one-half water is placed in it. The mailing tube is then covered with a piece of cotton cloth held in place by an elastic band. The colony is now ready for liberation and each day's output is sent by mail or otherwise to men in the field.

COLONIZATION OF SCHEDIUS

The first colonization of Schedius in New England was made in the fall of 1909. Colonies were liberated in five different towns. About 1,000 adults which issued from Japanese eggs were colonized. The others liberated were bred through a series of generations at the laboratory. In the spring of 1910 large numbers were liberated in 89 different towns. This colonization material was obtained from the stock used in the fall of 1909. Each year since 1910 Schedius has been colonized farther out from Melrose, Mass., with stock obtained in New England, until at present over 20,500,000 Schedius have been liberated and 358 towns in New England have been colonized. Three towns in Maine have been colonized, 95 in New Hampshire, 203 in Massachusetts, 31 in Rhode Island, and 26 in Connecticut. New Jersey has received nearly half a million Schedius, Washington, D. C., about 20,000, and Illinois 17,000. The Schedius were sent to the last two places in order to test their ability to attack the eggs of the tussock moth, which were abundant at the time of liberation. A few Schedius have been sent to Maxwell, N. Mex., in connection with the investigation of the range caterpillar (*Hemileuca oliviae*). About 200,000 specimens were sent to Madrid, Spain, in the fall of 1923, where they are being bred for liberation in a heavy gipsy-moth infestation in the Royal Forest near Madrid. *Schedius kuvanae* is not present in Europe, and this parasite, if successfully introduced, should develop into an important enemy of the gipsy moth in Spain. It is likely to prove more effective in Spain than in New England, because the summer season in Madrid is longer, allowing for more generations of Schedius to develop and the winters are less severe than in the United States.

The area which has been colonized in New England is shown in Figure 4.

Table I gives the colonization records in a much abbreviated form.

The colonization of Schedius is carried on during the fall, beginning about the middle of September and continuing into November, until the weather gets too cold for insect activity. As the colonies are prepared at the laboratory for liberation they are sent to men in the field for liberation or taken directly to the field for colonization. The colonies are placed from 1 to 2 miles apart where woodland and gipsy-moth infestations warrant it. Each tube contains 4,000 Schedius for liberation in suitable places in the area to be colonized. If the day is warm the Schedius are active and it is only necessary to remove the cloth top from the tube, when a few gentle taps will empty the tube of the parasites. The men liberating Schedius are supplied with a blue-print map, similar to that shown in Figure 11, indicating the roads in the town. The exact location of each colony is recorded on the map. In addition, a note is written giving the details of the colony site, so that the place may be visited at any later occasion. A roadside tree is marked with white paint with the letter "*S*" and an arrow pointing to the colony.

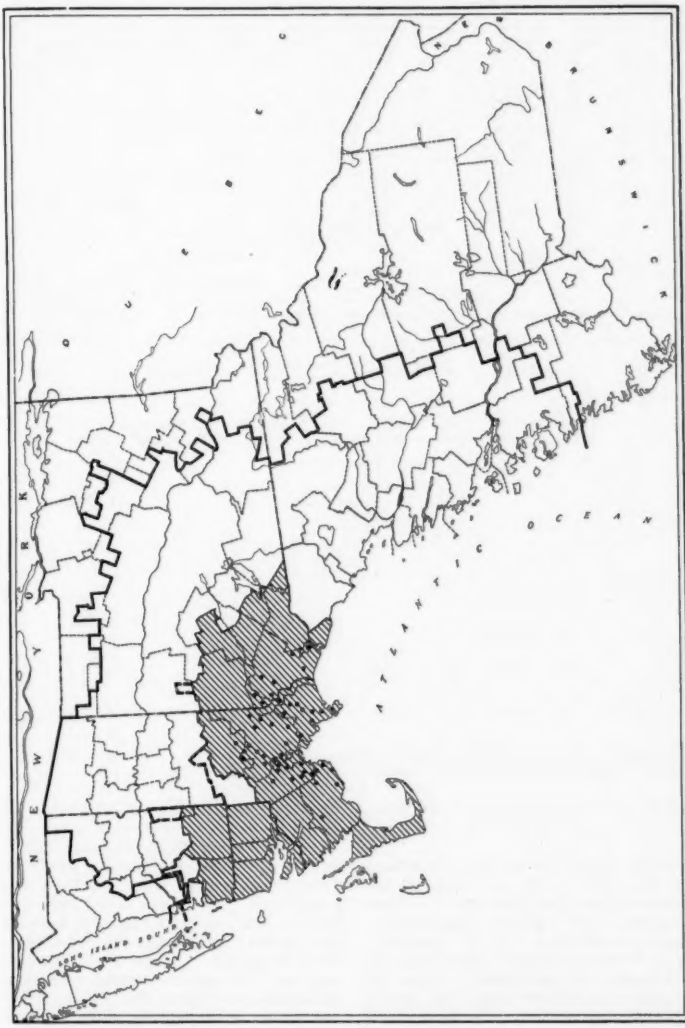

FIG. 4.—Map showing colonization of *Schedius kuvanae* in New England. The heavy black line is the quarantine line for the gipsy moth (*Porthetria dispar*), the area to the right of this line being infested by that insect. The shaded area has been solidly colonized with Schedius. The area between the broken line and the shaded area has been partially colonized with Schedius. The dots show the locations of the observation points from which egg collections have been made

TABLE I.—*Summary of the colonization of Schedius kuvanae*

Year	Massachusetts		New Hampshire		Rhode Island		Maine		Illinois	
	Colonies	Individuals	Colonies	Individuals	Colonies	Individuals	Colonies	Individuals	Colonies	Individuals
1909	6	46,415								
1910	89	889,120								
1911	9	68,486								
1912	7	93,368	2	19,807						
1913	111	382,645								
1914	247	1,120,536	252	944,725	2	21,855				
1915	108	455,146	52	182,308						
1916	234	1,477,963	265	1,161,929	15	57,200				
1917 [a]	3	9,120	343	1,006,279			77	232,260	3	5,000
1918	945	3,844,500	237	932,000						
1919			368	1,540,000						
1920					110	440,000				
1921	4	496,000			9	124,000			1	12,000
1922	26	200,000	16	516,000						
1923					118	472,000				
Total	1,789	9,083,299	1,535	6,303,048	254	1,115,055	77	232,260	4	17,000

Year	New Jersey		Connecticut		District of Columbia		Spain		Total	
	Colonies	Individuals	Colonies	Individuals	Colonies	Individuals	Colonies	Individuals	Colonies	Individuals
1909									6	46,415
1910									89	889,120
1911									9	68,486
1912									9	113,175
1913									111	382,645
1914									501	2,087,116
1915									160	637,454
1916									514	2,697,092
1917 [a]									426	1,252,659
1918									1,182	4,776,500
1919									368	1,540,000
1920	67	270,000							177	710,000
1921			219	1,638,875	1	20,000			234	2,290,875
1922	53	212,000	223	904,000					318	1,832,000
1923			201	804,000				[b] 200,000	319	1,476,000
Total	120	482,000	643	3,346,875	1	20,000		200,000	4,423	20,799,537

[a] A few eggs of *Hemileuca oliviae* parasitized by *Schedius kuvanae* were sent to Maxwell, N. Mex.
[b] Estimated colonies included in totals of colonies.

SUCCESS OF COLONIES AND DISTRIBUTION

Records obtained at the laboratory show that about 50 per cent of the colonies of Schedius liberated in Massachusetts and Rhode Island have become established. It is probable that in reality a higher percentage of the colonies are successful. Many of the collections of host eggs from which this percentage was obtained were made one or two years after the colony was liberated. This species is rather slow in increasing to sufficient numbers after its liberation to make it easily recovered. Schedius have been recovered from a total of 150 towns in New England. These recoveries have been made from 125 towns in Massachusetts, 15 in New Hampshire, 9 in Rhode Island, and 1 in Connecticut. The recoveries from the colonies in Maine and New Hampshire have been very poor, except in a few towns in southern New Hampshire. The broken black line in Figure 5 indicates the present dispersion of Schedius in New England. There have been occasional though infrequent recoveries of Schedius north of this line in Maine and New Hampshire. The recovery of Schedius from only one town in Connecticut is not a sign that the species will not do well in that State. No colonies were liberated there until the fall of 1921, and because of the scarcity of gipsy-moth eggs very few have been examined in an attempt to make recoveries.

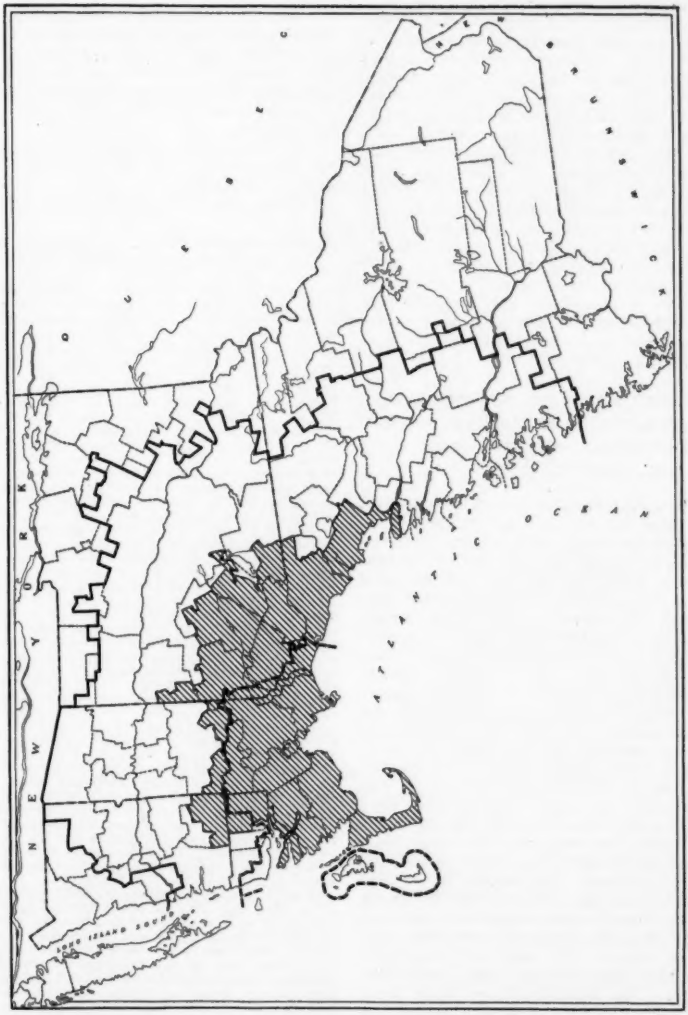

FIG. 5.—Map showing areas in New England from which *Schedius kuvanae* and *Anastatus bifasciatus* have been recovered. The outside heavy black line is the quarantine line for the gipsy-moth (*Porthetria dispar*), the area to the right of this line being infested by that insect. Anastatus has been recovered from the shaded area. Schedius has been recovered from the area inclosed within the broken black line

19977—25†——5

DISPERSION

Studies of dispersion of Schedius have continued over several years. The method used was to take the point of liberation of a colony as a center and run out lines from this center in the four cardinal directions. Along these lines at points equally distant from the center and consecutively from each other, collections of 10 or more gipsy-moth egg clusters were made. A study of the notes made from the examination of these eggs gave records of dispersion of 300 to 400 yards for the adults of a single generation, or a seasonal spread of over one-half mile. Dispersion records obtained late during the second fall after colonization have shown a spread of nearly 2 miles for the two seasons. Female Schedius are able to fly, and the wind may carry the adults considerable distances.

EARLY METHOD OF OBTAINING ANASTATUS BIFASCIATUS FROM IMPORTED GIPSY-MOTH EGGS FOR COLONIZATION

Anastatus adults were first reared at Melrose in the spring of 1908 from gipsy-moth eggs which were received from Japan and Russia during the winter of 1907 and 1908. This material was kept in a warm room, which hastened the issuance of the parasites. As the Anastatus began to emerge, they were placed with gipsy-moth eggs which had been kept in cold storage since the previous fall in an endeavor to retard the larval development. No reproduction occurred from this experiment, and the imported eggs containing the Anastatus were placed in cold storage to retard the issuance of the parasites until new gipsy-moth eggs were available. In July the imported material was removed from cold storage and 513 adult Anastatus issued and were liberated. During the fall of 1908 and the spring of 1909 large shipments of gipsy-moth egg masses were received from several European countries and from Japan. The largest quantity of the European material came from Hungary. The nonparasitized eggs were allowed to hatch and the remaining parasitized eggs were divided into equal lots for colonization. About 5,000 parasitized eggs were separated from the Japanese eggs and were added to the European colonization material.

DESCRIPTION AND LIFE HISTORY OF ANASTATUS BIFASCIATUS FONSCOLOMBE

Anastatus bifasciatus is now quite abundant in New England, and is often reared from eggs of the gipsy moth. It has previously been known as *Cynips bifasciata* Fonscolombe, *Eupelmus bifasciatus* Foerster, and *Eupelmus bifasciatus* Wachtl.

The early descriptions of this species are rather brief, and are obtainable in only a few libraries. A description, therefore, seems desirable at this time.

REDESCRIPTION (BY C. F. MUESEBECK, OF THE GIPSY MOTH LABORATORY)

FEMALE (fig. 6, *a*).—(Length 2.2 to 3 mm. Head transverse, more than twice as broad as thick anteroposteriorly, the eyes strongly divergent below; vertex finely transversely sculptured posteriorly, minutely punctato-reticulate anteriorly; frons mostly smooth and shining along the eye margins, scrobes strongly transversely sculptured; malar space nearly half as long as the eye, mostly punctato-rugulose, sometimes weakly so; malar groove distinct; ocellocular line about equal to the diameter of an ocellus; antennae inserted on a line with the lower extremities of the eyes or very slightly below; scape extending to the vertex; pedicel at least two-thirds as long as the first funicular segment; funicular segments becoming gradually shorter and broader, the sixth and seventh not distinctly as long as broad; club three-segmented, very nearly as long as the three last funicular segments combined; median lobe of mesoscutum completely strongly punctate, the lateral lobes very faintly lineolated or reticulate, and strongly shining; scutellum and axillae sculptured exactly like median lobe of mesoscutum; mesopleura finely lineolated, shining; propodeum polished; abdomen a little shorter than the thorax, broadening gradually from base to apex where it is broadly rounded, perfectly smooth at base, finely transversely lineolated posteriorly; ovipositor sheaths protruding very slightly beyond apex of abdomen. Head green, with purplish reflections; scape yellow; pedicel and flagellum bronzy-black; mesoscutum dark greenish bronze on the lateral lobes, purplish blue behind the median lobe which is a brilliant golden bronze; scutellum and axillae like the median lobe of mesoscutum except that they are tinged with green; propodeum purplish laterally; mesopleura brownish yellow, darker anteriorly; legs dark brown; wings hyaline with a small faintly fuscous spot at extreme base, and with two broad fuscous bands separated by a complete transverse curved hyaline band which arises directly before the stigmal vein; apex of wing hyaline; abdomen mostly greenish black with a large yellowish spot on first tergite.

MALE.—Length 1.8 to 2 mm. Head transverse, much more than twice as broad as thick anteroposteriorly; eyes very faintly and sparsely hairy; ocellocular line hardly as long as diameter of an ocellus; vertex and frons closely shallowly punctate; lower part of face confluently punctate, weakly so toward the malar furrows; cheeks faintly longitudinally sculptured; malar space more than half the eye height; antennae inserted about on a level with the lower eye margins; scape short, broad, slightly concave outwardly, and scarcely attaining vertex; pedicel very short, about one-third the first funicular segment; flagellum long, of uniform thickness; first segment of funicle twice as long as thick, longer than the second; second and third subequal, fourth, fifth, sixth, and seventh

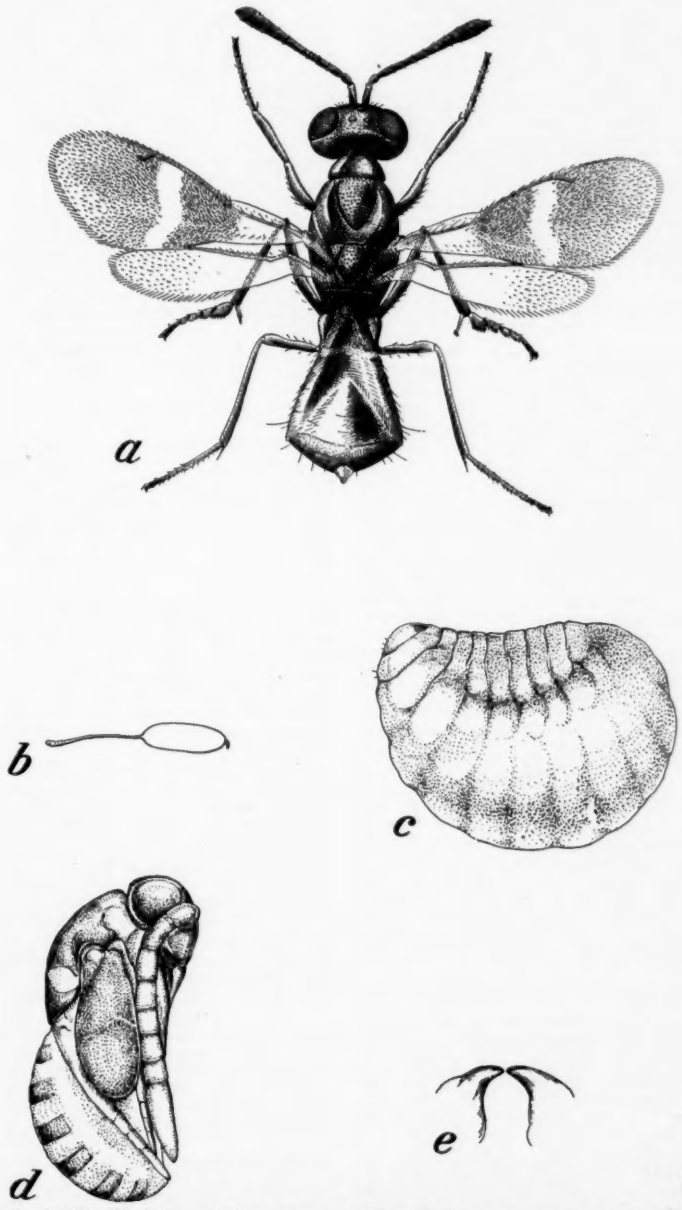

FIG. 6.—*Anastatus bifasciatus: a*, Adult; *b*, uterine egg; *c*, hibernating larva removed from host egg; *d*, pupa; *e*, mandibles. All greatly enlarged (Howard and Fiske)

gradually shorter, the seventh as broad as long; club not distinctly segmented, as long as the three last segments of funicle combined; mesoscutum, axillae, and scutellum rather evenly and minutely reticulato-punctate; propodeum very faintly reticulate, strongly shining, with a median longitudinal carina; spur of middle tibia longer than first tarsal segment; abdomen shorter than thorax, narrowest at base, smooth and shining, with a very faint suggestion of sculpture posteriorly. Head greenish, more or less aeneous black on vertex; antennae black, scape yellow below; thorax greenish black, scutellum bronzy black; pleura with bluish or purplish reflections; propodeum green; wings hyaline; all coxae and femora, base of anterior and middle trochanters and the posterior femora, except at base, black; posterior trochanters, all tibiae, and tarsi pale yellow; abdomen bluish black.

Described from many specimens reared from *Porthetria dispar* Linnaeus at the gipsy-moth laboratory

HABITS OF ADULTS AND ABUNDANCE IN THE FIELD

Investigations which have been made to determine whether the female Anastatus can fly have indicated that they can not. They jump well and are probably spread short distances by the wind. The males, which issue from hibernation a few days before the females, are often seen flying about the colonization cans in which they were colonized, apparently waiting for the issuance of the females.

Female Anastatus have been observed apparently feeding at the punctures they have made in gipsy-moth eggs, after oviposition or apparent oviposition. In laboratory experiments a mixture of about 40 per cent honey and 60 per cent water has been found the best food tried.

During the last two weeks of July and the first week of August Anastatus adults are found quite abundantly on the gipsy-moth eggs, as in *b* of Figure 2, in most of the area within which this parasite has been generally colonized. In a few locations where the parasite is especially abundant practically every egg cluster will have from 1 to 7 or 8 female Anastatus working on it, while many egg clusters have been observed with 10 to 15. As high as 22 female Anastatus have been seen on a single egg cluster.

OVIPOSITION AND IMMATURE STAGES

As soon as females of the gipsy moth begin their deposition of eggs in July, adults of Anastatus are present and occasionally are found on the abdomen of the female moth even before she begins to lay her eggs. When adults of Anastatus are abundant they begin parasitizing the gipsy-moth eggs almost as soon as they are laid and often five and six Anastatus are observed ovipositing in the eggs before the cluster is entirely deposited (fig. 2, *b*).

The Anastatus female requires less time for oviposition than does the Schedius. The time occupied by Anastatus females in ovipositing varies from 2 to 15 minutes, each oviposition averaging 4 or 5 minutes. S. M. Dohanian, an assistant at the laboratory, while making field observations on Anastatus, saw a single female apparently oviposit 42 times in 2 hours and 15 minutes.

The uterine egg, a hibernating larva, and a pupa of Anastatus are shown in Figure 6, *b*, *c*, *d*, and the larval mandibles in Figure 6, *e*. The parasite egg hatches very soon after oviposition and the resulting parasite maggot develops quickly into the hibernating stage (fig. 6, *c*; fig. 2, *e*), about three weeks being required for the entire development from egg to full-grown larva.

NUMBER OF GENERATIONS

Normally, Anastatus has only a single generation. The adults issue from the gipsy-moth eggs over a considerable period. A few begin to appear during the middle of June, and egg clusters collected as late as August 8, laid the previous year, have given adult Anastatus.

Issuance of Anastatus adults in June and in the middle of August are extremes. The main issuance of adults occurs during July, with the bulk of the Anastatus appearing during the last two weeks of that month. The dates vary with the season, but the heavy issuance occurs at about the time when the majority of the female gipsy moths are depositing egg clusters. The time spent by Anastatus within its host is usually about a year, although this period ranges in length from 10 to 13 months.

In some seasons a few Anastatus have two generations. Usually this is rare, but during the fall of 1921 it was commonly observed. Many egg collections received during the fall gave 2 and 3 per cent of fall issuance of male and female Anastatus. In several experiments these were mated and the females oviposited readily in gipsy-moth eggs. These parasitized eggs were kept through the winter, and during the following summer adult Anastatus issued. In most cases they were males, but there is at least one record of both sexes maturing in the second generation.

The experiment here described was so unusual in its results that it is worth recording. On July 9, 1921, a small breeding tray was stocked with 1,278 new gipsy-moth eggs. Honey-and-

water solution on blotting paper was put in the tray and 150 adult Anastatus which had issued from hibernation at about this time were introduced. The female Anastatus began to oviposit immediately. The gipsy-moth eggs were examined on August 9 and many Anastatus pupae were seen. From August 10 to 20, 172 male and 28 female Anastatus issued. A few days later 18 more adults appeared; the sex was not noted. An examination of the eggs showed that 50.3 per cent of them had been parasitized by Anastatus, and of this 50.3 per cent, 17 per cent had issued and 33.3 per cent were typical hibernating Anastatus larvae. The hibernating larvae were kept through the winter, and the following summer 75.9 per cent of them issued.

The adult Anastatus from this experiment, together with others which issued during the fall from field-collected gipsy-moth eggs, were used in reproduction experiments. These females of the fall generation were observed to mate and to oviposit. The eggs in which they deposited were saved through the winter and adult Anastatus issued from many of them in the following summer.

LONGEVITY EXPERIMENTS

In laboratory trays adult Anastatus are short-lived as compared with the adults of Schedius. They usually do not live much more than 10 days to 2 weeks. Occasionally adults have lived in confinement for 3 weeks.

Cold storage experiments have shown that the Anastatus larvae can live over a long period. Gipsy-moth eggs containing Anastatus hibernating larvae were collected in the spring and placed in cold storage at a temperature of about 30° F. There they were kept until a year from the following July, when they were brought to the laboratory. In August both sexes of adults issued, the Anastatus larvae having lived two years within the host egg. These females oviposited successfully in new gipsy-moth eggs, and the following summer their progeny issued.

REPRODUCTION ON GIPSY-MOTH EGGS

Normally, Anastatus oviposits in fresh gipsy-moth eggs and its larva develops quickly, consuming the entire egg contents before the gipsy-moth embryo develops. Occasionally it is found ovipositing in the field in gipsy-moth eggs which have developed. Laboratory reproduction experiments have been successful, using gipsy-moth eggs in which the embryo was fully developed. A generation of Anastatus has also been developed on dead gipsy-moth eggs which had been placed in cold storage before the gipsy-moth embryo had developed.

REPRODUCTION ON EGGS OTHER THAN THOSE OF THE GIPSY MOTH

Anastatus females attack the eggs of the gipsy-moth more freely than they do the eggs of other insects to which they have been given access in laboratory cages. Females have been confined in cages with various lepidopterous eggs, but oviposition, with reproduction, has not been observed in these experiments except on the eggs of *Hemileuca oliviae* and *Hemerocampa leucostigma*.

REPRODUCTION ON APANTELES MELANOSCELUS RATZ.

During the years 1921, 1922, and 1923 over 87,000 cocoons of *Apanteles melanoscelus* were collected from the field in New England for reproduction and rearing. It was necessary to isolate each of these cocoons because of the enormous amount of hyperparasitism. From this great mass of material four adults of *Anastatus bifasciatus* have been reared.

WINTER MORTALITY OF ANASTATUS

During a severe winter in New England there is a large mortality of unprotected gipsy-moth eggs and of hibernating Anastatus. This fact was very evident in the large collections of gipsy-moth eggs which were made during the winter of 1917–18 to obtain Anastatus for colonization.

During this winter about 79 per cent of the Anastatus in the eggs under observation were killed. This figure was obtained from 52,800,000 gipsy-moth eggs, which contained 8,349,000 Anastatus larvae. Most of these eggs were collected at Peabody, Mass. The lowest temperatures for the winter recorded at the gipsy moth laboratory were observed on December 30, 1917, and February 2, 1918, when the readings were —14° and —15° F., respectively.

The collections of gipsy-moth eggs made south of Boston during the winter showed a much lower mortality of Anastatus, and in some areas there was practically no winter killing.

To determine the winter mortality of Anastatus, collections of gipsy-moth eggs were made during the spring of 1922 and 1923 from points scattered over the area where it was well established. The collections showed

for the entire area an issuance of 67.2 per cent of the Anastatus in 1922 and 79 per cent in 1923. The laboratory thermograph at Melrose Highlands, Mass., recorded —15° F. in February, 1922, and —13° F. in February, 1923. Egg clusters collected below and above the snow line were kept separate, and the issuance of Anastatus recorded. It was found that of the eggs collected in 1922 the issuance from those below the snow line was 90.6 per cent, from those above the snow line 49 per cent, and the average of all was 67.2 per cent. Of the eggs collected in 1923 the issuance from those below the snow line was 82.2 per cent, from those above the snow line 76.3 per cent, and the average was 79 per cent.

Among the gipsy-moth eggs from which these figures were obtained were many collected from the northern part of the area colonized with Anastatus. The average mortality of Anastatus in the area south of Melrose is not nearly so great as it is north and northwest of this town. There are many winters with practically no mortality of Anastatus over the eastern half of Massachusetts, southeastern New Hampshire, and southwestern Maine.

During the spring of 1923 collections of gipsy-moth eggs were made from high land, as from the tops or near the tops of hills, and also from low land, as along the banks of rivers or brooks or the edge of a swamp or meadow. The eggs taken below the snow line and those from above it in each set of collections were kept separate. The percentages of issuance of Anastatus were, for the eggs taken from the high land, 85 for those above and 90 for those below the snow line, and for the eggs from the low land, 67 for those above and 88 for those below the snow line.

The collections indicate that there is considerably more winter killing of Anastatus in the low areas than in the higher ones, and that the snow in either location offers very good protection to Anastatus.

FIELD WORK TO OBTAIN ANASTATUS FOR COLONIZATION

The first collections of gipsy-moth eggs from New England to secure Anastatus for further colonization work were made in the fall of 1909. Most of the eggs were collected in the vicinity of the centers of four of the five colonies which had been established in the summer. Each season thereafter for some years collections of large numbers of gipsy-moth eggs were made at different colonies suitably located (Fig. 7, *a*). Using the exact point of liberation of the colony as a center, eight lines were run, four to the cardinal points of the compass and the other four intermediate to them. The first year or so collections of gipsy-moth eggs were made at 25-foot, 50-foot, and 100-foot intervals along the lines as far out from the center as Anastatus was found. In this manner the area was determined where the parasitism by Anastatus was high enough to warrant the general collection of gipsy-moth eggs to obtain Anastatus for colonization.

As Anastatus spread and the lines became longer, the greater part of the work was done in a colony convenient to the laboratory at Peabody, Mass. A chart of the area covered is shown in Figure 8. At this colony the lines were run farther from the center each year in order to determine the area from which to collect as many egg clusters as possible. General collection of eggs was made in the area where the eggs showed as high as 10 per cent parasitism. This work was not confined to the Peabody area alone, but for a number of years most of the material collected came from that area.

Year after year these lines continued outward until several of them extended 3 miles from the center. Collections of 10 egg clusters each were made at the center and at intervals of 100 feet along the lines for 600 feet; then at intervals of 100 yards as far as the collections showed parasitism by Anastatus. These sample collections were examined at the laboratory and the percentage of parasitism in each case was ascertained. From the data thus acquired the area for general collection of eggs was determined. The collections made in 1915 and later do not show the spread from the original colony, for in the spring of 1915 the outside sections of Peabody and the surrounding towns were colonized with Anastatus and some of this newly colonized area was included within the 10 per cent limit.

The increase year by year in the area which included the points showing a parasitism of at least 10 per cent, and in which most of the egg masses were collected, is here presented:

Year	Acres occupied
1910–11	1. 7
1911–12	2
1912–13	12
1913–14	234
1914–15	242
1915–16	903
1916–17	2, 261
1917–18	3, 915
1918–19	8, 008
1919–20	8, 198

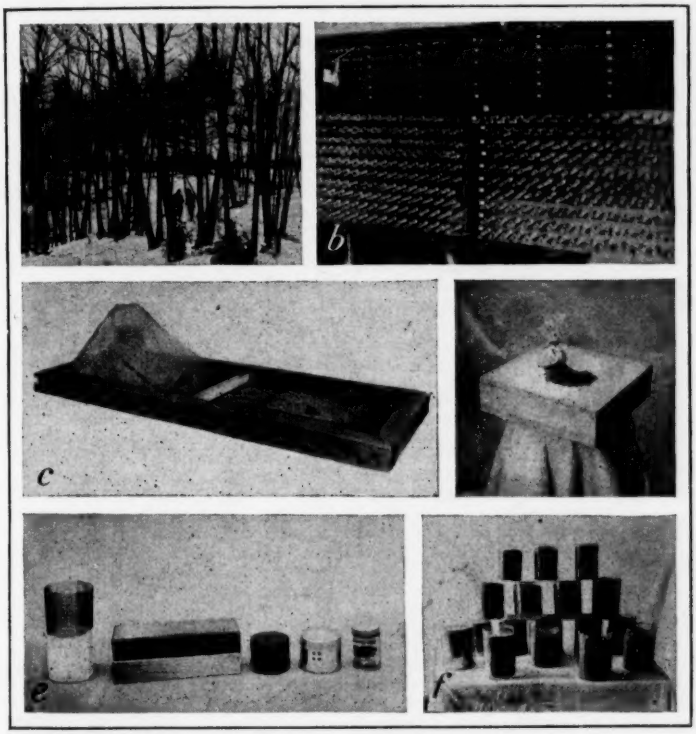

FIG. 7.—*Anastatus bifasciatus* and its colonization: *a*, Collecting gipsy-moth eggs to obtain Anastatus for colonization; *b*, trays used for hatching the nonparasitized gipsy-moth eggs; *c*, interior of tray after the hatching of the gipsy-moth eggs is complete (mosquito netting full of webbing left by first-stage gipsy-moth larvae before they entered the glass tubes and were removed); *d*, hand-sifting tray; *e*, types of colonization cages for Anastatus, the two on the right being the most satisfactory; *f*, six bushels of gipsy-moth eggs after having passed through the separating apparatus, the eggs being in the proper condition to be run through the bouncing apparatus. In *b* and *c* are shown methods used in preparing Anastatus for colonization before the apparatus shown in Figure 9 was developed

The extent of this work has varied in different years. In some seasons 5 to 6 bushels of gipsy-moth eggs have been collected, and one winter about 9 bushels were gathered. The greatest number of eggs handled at the laboratory in one season amounted to more than 98,000,000 in the winter of 1918–19. On an average, about 10 per cent of these were parasitized.

For the first few years after Anastatus became established, most of the gipsy-moth egg clusters were collected near the centers of the few colonies which had been liberated. The eggs were so kept as to allow the nonparasitized gipsy-moth eggs to hatch, and the remaining material was divided for colonization in the spring.

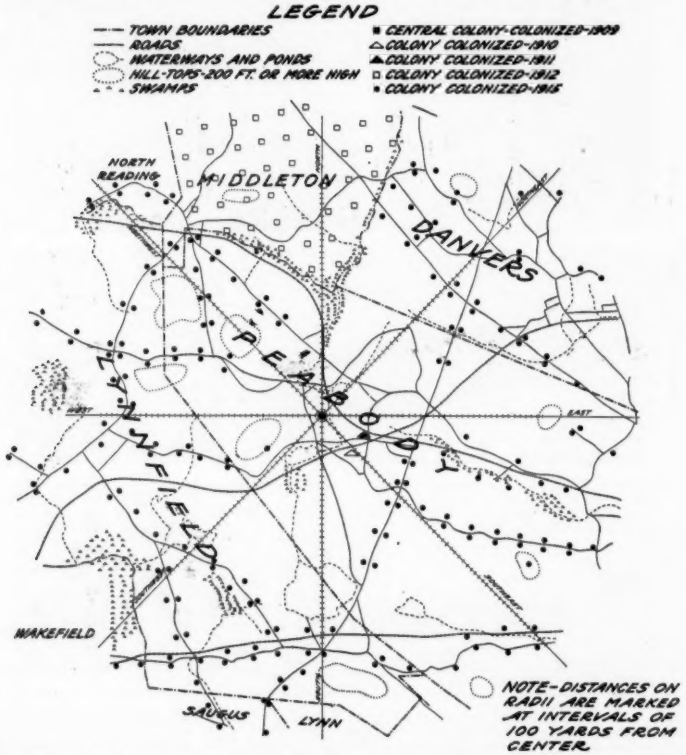

FIG. 8.—Chart showing area at Peabody, Mass., where some of the records of dispersion and percentage of parasitism by Anastatus were obtained. The checks on the eight lines are 100 yards apart and show the points where the sample collections of gipsy-moth eggs were made. The different marks on the chart show the location of Anastatus colonies liberated in this area during the different years. Scale, 1 inch=1.7 miles

LATER LABORATORY METHODS USED IN HANDLING GIPSY-MOTH EGGS TO OBTAIN ANASTATUS BIFASCIATUS FOR COLONIZATION

Each fall small samples of gipsy-moth eggs from different locations are collected and examined to determine the percentage of parasitism by Anastatus. To obtain Anastatus for colonization, large collections of egg masses are then made at the points where the parasitism is 10 per cent or more.

The collections of egg masses increased from year to year until as many as 9 bushels of gipsy-moth egg clusters were collected and handled in one season at the laboratory. The methods used to separate the eggs containing parasites from the rest of the material have varied considerably and have been gradually improved until at present much of the work is practically mechanical. These improvements have resulted in a large saving of time and expense.

In order to handle the eggs in a satisfactory manner it was necessary first to separate them from the mass of hairs in which the female moth had packed them. This was originally done by rubbing the egg clusters with the bare hand or with a pad over a piece of cotton cloth, drawn tightly over a tray, as in Figure 7, *d*, until the hair had been rubbed through the cloth, leaving only the eggs on the cloth. A machine on the principle of the gristmill is now used to do this sifting. This machine, shown in Figure 9, *a* and *b*, has two disks about 3 feet in diameter, the lower one of which is stationary, while the upper revolves, the power being furnished by a small motor. The inner surface of each disk is padded with felt covered by canvas. The upper disk rests on a spindle, and can be adjusted so as not to injure the eggs. The broken egg clusters are fed into the machine through a boxlike opening in the upper disk; as this disk revolves the eggs are gently rubbed between the two inner surfaces. As the eggs are worked to the circumference of the disks they become separated, cleaned, and drop off, assembling in a jar below (fig. 9, *a*). The hair and dust from the egg clusters are removed by means of a blower attached to the center of the apparatus.

This apparatus is not only a great labor saver, but by cleaning the dust and hair from the eggs it eliminates to a large extent the irritation of the nose and throat, which has at times severely affected most of the men at the laboratory.

After the eggs have been cleaned (fig. 7, *f*) they are ready for the separation of the parasitized eggs. Formerly the eggs were placed in trays (fig. 7, *b*) until the hatching of the nonparasitized eggs was completed. The cleaned eggs were spread evenly over the bottoms of the trays. In the front of each tray are numerous 1-inch holes, the use of which will be explained later. In each tray, on top of the layer of eggs, was placed one or two thicknesses of cloth mosquito netting, through which the small caterpillars had to crawl on leaving the tray. A considerable part of the web spun by the crawling larvae was caught in this netting (fig. 7, *c*). When the eggs and netting were in place each tray was entirely covered with black paper and placed on racks in a warm room to allow the nonparasitized eggs to hatch. Before it was time for the eggs to hatch the paper was broken over the holes in the front of each tray and glass vials were inserted (fig. 7, *b*), into which the caterpillars crawled. When hatching began the entire attention of several men for nearly two weeks was required to remove the larvae from the glass tubes. This was best accomplished by cleaning out each tube with a camel's-hair brush and placing the caterpillars in kerosene. This method was later much improved upon by using a vacuum cleaner with a special attachment which fitted into the tubes.

After hatching was completed the black-paper tops were taken from the trays and the mosquito netting was removed, with much of the webbing left by the crawling caterpillars. The remaining material was separated as well as possible by allowing the air from an electric fan to pass over it, blowing out some of the eggshells and light, dead eggs. This separating process was greatly improved by the development of a machine (fig. 9, *d*) so constructed that as the parasitized eggs, dead eggs, and eggshells ran down a chute the dead eggs and eggshells were drawn off by suction, while the parasitized eggs, which are heavier than the other material, assembled in a glass tube at the bottom of the apparatus.

This method of allowing the nonparasitized gipsy-moth eggs to hatch so that the parasitized eggs could be separated from the rest of the material was a long and tedious process and has been discontinued except for small experiments. Now a simple apparatus called a bouncing machine (fig. 9, *c*) is used. The eggs are allowed to run down a wooden chute, at the bottom of which is a small piece of tin placed at right angles to the inclined surface. This piece of tin is termed a "take-off"; when the eggs hit it they bounce into the compartments of a box beneath. The eggs containing parasite maggots do not have the same capacity for bouncing as the healthy gipsy-moth eggs and therefore fall into the first and second compartments, while the other eggs bounce farther and drop into the compartments beyond. The nonparasitized eggs are then destroyed. The eggs containing parasites are put into small manila envelopes in lots of about 1,000 parasites each for colonization in the spring. These parasitized eggs are not actually counted, but are measured in a small glass tube so graduated that each colony will contain 1,000 eggs.

COLONIZATION OF ANASTATUS

The first colonization of Anastatus in America was made in 1908, when 513 adults were liberated. Most of these

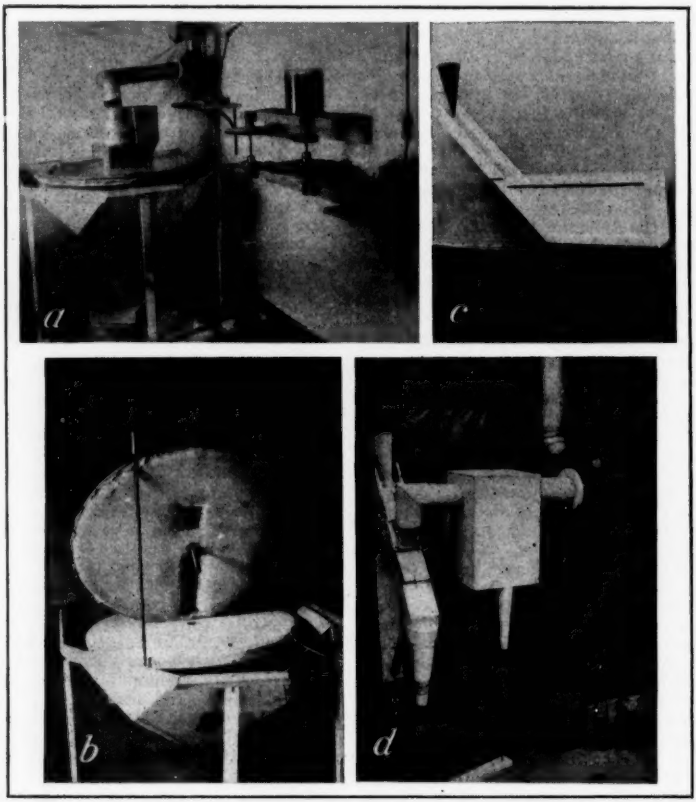

FIG. 9.—Apparatus used in colonization of egg parasites of the gipsy moth: *a*, Separating apparatus, used to separate gipsy-moth eggs from the hair; *b*, showing inner surfaces of disks of separating apparatus; *c*, bouncing apparatus, used to separate nonparasitized gipsy-moth eggs from eggs containing Anastatus larvae; *d*, winnowing apparatus, used for separating the eggs containing Anastatus larvae from the egg-shells, dead eggs, and other matter removed from the hatching trays

Anastatus were reared from gipsy-moth eggs collected in Russia and sent to the laboratory; a few came from Japanese eggs. In 1909 the Anastatus were colonized as mature larvae within the host eggs. Most of this material was received from Hungary, but it included about 5,000 Anastatus from Japan.

298 towns are in Massachusetts, 169 in New Hampshire, 97 in Maine, 35 in Vermont, 32 in Rhode Island, and 31 in Connecticut. The area which has been colonized by Anastatus is shown in Figure 10. No further colonization of Anastatus is necessary in 441 of these towns, so thoroughly has the work been done. In the other

TABLE II.—*Summary of the colonization of Anastatus bifasciatus*

	Massachusetts		New Hampshire		Maine		Rhode Island	
	Colonies	Individuals	Colonies	Individuals	Colonies	Individuals	Colonies	Individuals
1908	1	513						
1909	5	128, 180						
1910	97	105, 000						
1911	160	227, 500	26	26, 000				
1912	621	621, 000						
1913	851	851, 000	571	571, 000				
1914	1, 047	1, 047, 000	514	514, 000				
1915	6, 877	6, 877, 000	1, 501	1, 501, 000	813	813, 000		
1916	8, 218	8, 227, 000	3, 522	3, 522, 000	942	942, 000		
1917	1, 722	1, 722, 000	4, 376	4, 376, 000	1, 357	1, 357, 000	573	573, 000
1918 [a]	645	645, 000	575	575, 000	377	377, 000	93	93, 000
1919	1, 946,	2, 111, 000	6, 130	6, 273, 000	1, 479	1, 675, 000	69	135, 000
1920			1, 154	1, 214, 000				
1921	2	[b] 500, 000						
1922	1, 854	3, 708, 000	408	816, 000	121	242, 000	129	258, 000
1923	333	333, 000	225	225, 000	167	167, 000		
Total	24, 379	27, 103, 193	19, 002	19, 613, 000	5, 256	5, 573, 000	864	1, 059, 000

	Connecticut		Vermont		Total	
	Colonies	Individuals	Colonies	Individuals	Colonies	Individuals
1908					1	513
1909					5	128, 180
1910					97	105, 000
1911					186	253, 500
1912					621	621, 000
1913					1, 422	1, 422, 000
1914					1, 561	1, 561, 000
1915					9, 191	9, 191, 000
1916					12, 682	12, 691, 000
1917	51	51, 000			8, 079	8, 079, 000
1918 [a]	55	55, 000			1, 745	1, 745, 000
1919	144	144, 000			9, 768	10, 338, 000
1920					1, 154	1, 214, 000
1921					2	500, 000
1922	215	430, 000	56	112, 000	2, 783	5, 566, 000
1923	200	200, 000	5	5, 000	930	930, 000
Total	665	880, 000	61	117, 000	50, 227	54, 345, 193

[a] Enough eggs of the gipsy moth were collected this year to obtain from them 8,000,000 Anastatus. The winter of 1917–18 was very severe, with heavy mortality of both host and parasite.
[b] Estimated. The greater part of the material was used for a large reproduction experiment.

Table II presents statistics of the yearly colonization. Since 1909 all Anastatus which have been liberated have been obtained by collecting gipsy-moth eggs in New England. As a rule, each colony has contained 1,000 Anastatus. They have been put out as full-grown larvae within the gipsy-moth eggs.

Over 54,000,000 Anastatus have been liberated in New England, distributed over 662 towns. Of these, 221 towns the colonies were liberated rather sparsely, as the gipsy-moth infestations at the time of colonization were light and scattering. It will be necessary to place more colonies of Anastatus in many of the partially colonized towns.

During the winter months the Anastatus which are to be colonized in the spring are gathered from the field, in the gipsy-moth eggs. After separating the parasitized from the healthy

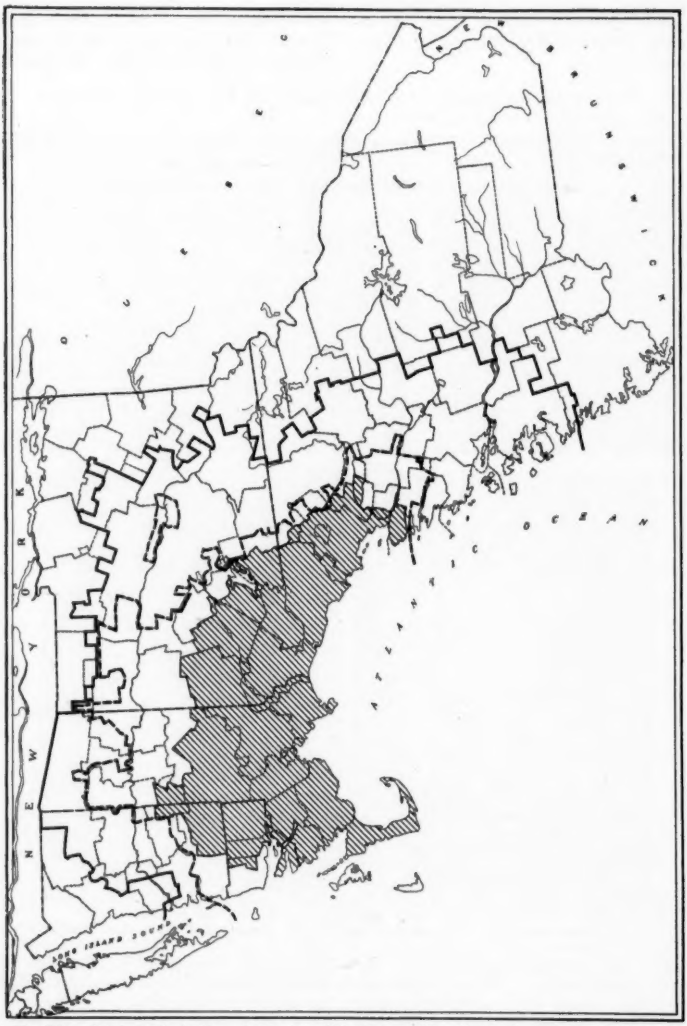

FIG. 10.—Map showing colonization of *Anastatus bifasciatus* in New England. The heavy black line is the quarantine line for the gipsy moth, the area to the right of this line being infested by that insect. The shaded area has been solidly colonized with Anastatus. The area between the broken line and the shaded area has been partially colonized with Anastatus

gipsy-moth eggs 1,000 parasitized eggs are put into small manila envelopes and stored in a cool place until the roads can be traveled in the spring. In some seasons the work of colonization has required a considerable force of men and auto vehicles in order to liberate the colonies in the limited time available. In several cases the various States have assisted greatly in the work.

The men are supplied with large blue-print maps (fig. 11) showing all roads in the towns to be colonized. Each man is given a supply of colonies and small tin cans (fig. 7, *e*, at right). Each can has three ⅛-inch holes in its side near the top. All of the roads in each town are traversed and a colony of 1,000 Anastatus is liberated on each side of the road at intervals of a quarter of a mile, if there is woodland area with sufficient gipsy-moth infestation to warrant such frequency. The colonies are placed 100 to 200 feet from the roadside. The can is nailed to a tree trunk in an inconspicuous place (fig. 2, *f*) and the parasitized eggs are poured into the can. A tight-fitting cover is placed on each can to prevent the rain and birds from destroying the colony. The location of each colony is marked on the blue-print map of the town (fig. 11). In each town two colonies in easily accessible locations are marked in the field by painting with white paint on a roadside tree a letter "A," with arrows pointing to the center of the colony (fig. 2, *c*). A note for filing at the laboratory is written, giving directions so that the marked colonies can be easily located later.

SUCCESS OF COLONIES AND DISTRIBUTION OF ANASTATUS

Collections of gipsy-moth eggs for data in regard to the establishment of Anastatus after colonization have shown that this parasite is easily established and recovered. Eighty to 90 per cent of the colonies liberated in Massachusetts, where collections of host eggs have been made later, have given proof of its presence.

About 50 per cent of the collections of gipsy-moth eggs which have been made in the other New England States showed the presence of the parasite. Anastatus has been recovered from 161 towns in Massachusetts, 75 in New Hampshire, 20 in Maine, 8 in Rhode Island, and 2 in Connecticut, or 266 in all.

Anastatus are now being found in gipsy-moth eggs sent to the laboratory from practically every town where the species has been thoroughly colonized. Figure 5 shows the area from which Anastatus has been recovered. It should be noted that the species is much more hardy than Schedius and is being recovered from the towns in the northern part of the colonized area.

PERCENTAGE OF ISSUANCE OF ADULT ANASTATUS FROM THE COLONIZATION CANS

The contents of many colonization cans have been examined at the laboratory. Cans showing a low percentage of issuance of Anastatus adults have occasionally been found. More than half of the cans which have been brought to the laboratory have shown that over 90 per cent of the parasitized eggs had yielded Anastatus adults. The average percentage of issuance is 68 for all the cans which have been collected.

DISPERSION

Very careful records were kept of the spread of Anastatus during the first years after its establishment in Massachusetts. Gipsy-moth egg clusters were collected along lines run in eight directions from the centers of several colonies. At first the egg collections were made at 50-foot intervals. Later, as the spread became greater, the collections were made along the lines at intervals of 100 feet for the first 600 feet, and then of 100 yards to points well beyond the recovery of the parasite. The examination of the eggs collected showed for the first year a spread of about 200 feet, and for the second, 500 feet.

Similar collections were made in the following years until later liberations of parasite colonies interfered with the data desired. These collections showed that after a colony became well established the annual spread measured from its center was very much greater than it was in the first year or two. The data were obtained from five widely separated towns, and the spread was similar at each of the five colonies under observation. An amazing increase in the rate of dispersion was noted as year succeeded year and the colonies became stronger. For the first year after the five colonies were liberated the spread from each center was 200 feet, and for the second year 500 feet. For the third year the average spread was 890 feet, and the extreme spread

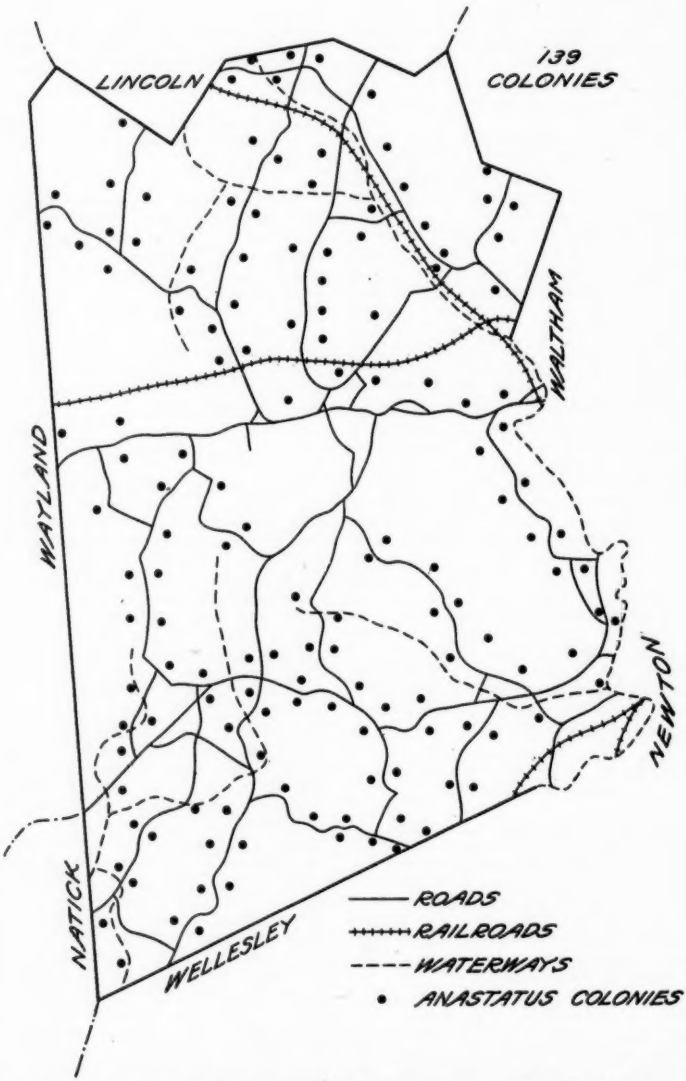

FIG. 11.—Copy of blue-print map of town showing location of Anastatus colonies. Each dot represents a colony of 1,000 Anastatus. Scale, 1 inch=4.35 miles

1,100 feet. For the fourth and fifth years the averages were 2,520 and 4,650 feet, and the extreme spreads 3,600 and 4,800 feet, respectively.

There seemed to be very little evidence in these collections to indicate that Anastatus spread more rapidly in one direction than in another. The spread to the north and northwest was greatest in some colonies, but other colonies showed the greatest dispersion in the opposite direction. The wind probably is an important factor in the dispersion of this parasite, for the female is not known to fly, although it has great jumping ability, and if a gentle wind stirs it into activity, causing it to jump often, it would without doubt be carried considerable distances. The nature of some of the recoveries indicates strongly that the females are blown distances of 300 and 400 yards, for several collections of gipsy moth eggs made along the same line a hundred yards apart often show no presence of Anastatus, although the species will be found present in the eggs collected farther from the center.

PERCENTAGE OF GIPSY-MOTH EGGS PARASITIZED BY ANASTATUS

In order to ascertain the amount of parasitism of the gipsy-moth eggs by the introduced parasites, collections of the host eggs have been made each year from many points over the infested area. The percentage of parasitism by Anastatus which has been found in a majority of the collections is very encouraging.

The gipsy-moth eggs collected from the colony sites usually show the presence of Anastatus the year after colonization. In such cases the amount of parasitism is small, but it increases year after year until the maximum is reached. Because Anastatus spreads only short distances some gipsy-moth eggs which are collected in the newly colonized territory, but not from colony sites, often show no parasitism.

Very many collections of host eggs have been made to determine the percentage of parasitism. This work has been carried on most intensively in the areas which have been colonized longest, and for the most part at Peabody, Mass., and neighboring towns.

Each sample collection of eggs contained, when possible, 10 egg clusters. A collection was made at the center and along eight lines, from the center to the four cardinal and the four intermediate points. The collections within 600 feet of the center were made at intervals of 100 feet, and at greater distances at intervals of 100 yards.

The collection of gipsy-moth eggs was carried on intensively at Peabody from 1910 until the spring of 1921. The parasitized eggs obtained were used for new Anastatus colonies. The information obtained by the examination of these sample collections was found useful in determining the area over which it would be practical to do general collecting to obtain Anastatus for colonization.

A summary of the percentage of parasitism obtained from the Peabody collections is presented in much abbreviated form in Table III. Figure 8 shows the points where the egg collections were made.

At Peabody the first colony of Anastatus was liberated in 1909. In 1910 another colony was liberated, and a third in 1911. The 1910 colony was liberated about 1 mile southeast, and the 1911 colony about one-fourth mile nearly east, of the 1909 colony.

TABLE III.—*Parasitism of eggs of the gipsy moth collected at and near Peabody, Mass., for the specified years and distances from center of colony*

Year eggs collected	At center	From center to 600 feet	From 200 yards to 1,400 yards	From 1,400 yards to 2,300 yards	From 2,300 yards to 3,600 yards	From 3,600 yards to 4,500 yards	From 4,500 yards to 5,000 yards
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1910–11		18					
1911–12	33	19	1				
1912–13	17	17					
1913–14	31	28	8				
1914–15	20	21	9				
1915–16	29	27	17	6	3	1	1
1916–17	32	26	19	12	7	1	3
1917–18	26	22	24	18	16	17	18
1918–19	4	19	20	18	21	15	17
1919–20	19	20	17	16	14	13	16
1920–21	29	27	18	22	17	17	18

No more Anastatus were liberated in this area until the spring of 1915, when the outside area of Peabody and the surrounding towns were solidly colonized with Anastatus. The effect of this later colonization is shown in the evenness of parasitism manifested in the collections made 2 and 3 miles from the center of the original Peabody colony.

After 1921 the gipsy-moth infestation in this area was too light for general collection of eggs to obtain Anastatus for colonization. In each of the following years sample collections of gipsy-moth eggs when possible of 10 egg clusters each, have been made to determine the percentage of parasitism in this area. About 40 collections were made at points scattered over the area where general collecting was previously done. The average percentage of parasitism of these eggs by Anastatus has been, for 1921–22, 33; for 1922–23, 23; and for 1923–24, 18.

In order to determine the average percentage of parasitism by Anastatus of the gipsy-moth eggs in a town which should be representative several years after colonization, 10 egg masses were collected from about 50 points in the town of Weston, Mass. The egg collections were made in the woodland near the roadside or from roadside trees. Each road in the town was included in the survey. The average percentage of parasitism of the gipsy-moth eggs for each year during the time covered by the survey was, for 1917–18, 21; for 1918–19, 19; for 1919–20, 13; for 1920–21, 33; for 1921–22, 34, and for 1922–23, 21.

During the last five years representative collections of gipsy-moth eggs have been made from the following five towns in Massachusetts: Burlington, Dover, Lynnfield, North Reading, and Wilmington. About 17 points were chosen in each town and collections of 10 egg clusters when possible were made at each location. The average percentages of parasitism of the gipsy-moth eggs by Anastatus for the five years in each town are shown in Table IV.

The figures for the year 1921–22 show the maximum percentage of parasitism of gipsy-moth eggs by Anastatus which has been obtained over a large area in Massachusetts since the establishment of this parasite in New England.

TABLE IV.—*Average percentage of parasitism of gipsy-moth eggs by Anastatus bifaciatus as indicated by representative collections made in five towns in Massachusetts*

Year	Burlington	Dover	Lynnfield	North Reading	Wilmington
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1919–20	14	14	11	16	16
1920–21	24	34	19	23	26
1921–22	35	37	31	35	34
1922–23	32	31	28	25	30
1923–24 *	28	24	14	11	18

* The collections of 1923–24 were made somewhat earlier than usual, possibly before some of the Anastatus were through ovipositing; the percentage of parasitism is therefore thought to be rather low.

PERCENTAGE OF PARASITISM BY ANASTATUS AND SCHEDIUS OF GIPSY-MOTH EGG CLUSTERS AT VARIOUS HEIGHTS IN THE TREES

Collections of gipsy-moth eggs to determine the percentage of parasitism by Anastatus and Schedius of the eggs at different heights in the trees have shown that the parasitism is approximately the same over the entire tree. The collections of eggs for data on Anastatus were made in four separate locations. The egg clusters collected from the trees at distances of from 1 foot to 6 feet from the ground were termed "low-point" collections; those collected at heights of from 20 to 55 feet were termed "high-point" collections. Five egg clusters were collected at the low and five at the high points from each of the trees selected in the four locations. Table V contains a summary of the examinations of the eggs.

The average percentage of parasitism of the eggs collected from the low points was 37.0, and for those from the high points 35.8. The difference between the average size of the lower egg clusters and that of the higher could account for this difference, the higher being slightly the larger. Studies of the percentage of parasitism of egg clusters of different sizes have shown that the percentage of parasitism increases as the size of the cluster decreases.

TABLE V.—*Percentage of parasitism by Anastatus bifaciatus of gipsy-moth egg clusters collected at different heights in the trees*

Distance from ground eggs were collected	Number of egg clusters	Percentage parasitized by Anastatus	Average number of eggs in each cluster
1 foot to 6 feet	40	40.2	202
1 foot to 6 feet	40	30.7	273
1 foot to 6 feet	40	39.7	165
1 foot to 5 feet	40	37.5	205
Average		37.0	211
35 feet to 40 feet	40	35.5	280
20 feet to 35 feet	40	28.2	326
30 feet to 55 feet	40	42.3	127
35 feet to 40 feet	40	37.1	237
Average		35.8	242

Similar collections of gipsy-moth eggs have been made in areas where Schedius was abundant, to determine its parasitism of the eggs on various parts of the trees. Only a slight difference was found in the activity of Schedius at different heights, the average percentage of parasitism at less than 6 feet from the ground being 26, and that for heights of from 30 to 55 feet 29. This difference could be explained by the fact that the higher egg clusters averaged only 154 eggs each, while those collected at heights below 6 feet averaged 171 eggs.

PERCENTAGE OF PARASITISM BY ANASTATUS AND SCHEDIUS OF GIPSY-MOTH EGGS COLLECTED AROUND OBSERVATION POINTS

During 1911 and 1912 about 250 points, scattered over a considerable part of the area at that time infested by the gipsy-moth, were chosen and called "observation points." A tree at the center of each point was marked and a circle 100 feet in diameter was described around it. Careful records of the condition of the growth and intensity of the gipsy-moth infestation at each point have been kept for each year.

From 1912 through 1923 collections of gipsy-moth eggs have been made around many of these points. In each case an attempt was made to have a typical sample of eggs from which to determine the amount of egg parasitism. The eggs were collected just outside the 100-foot circle in eight different directions from the center. Two large, two medium, and two small egg clusters were collected at each of the eight places, a total of 48 egg clusters for each observation point. Each cluster was separately examined at the laboratory. The results are presented in Table VI.

The area covered by the observation point collections is shown in Figure 4. It will be seen that the eastern part of Massachusetts and the southeastern part of New Hampshire are well represented. The egg collections were not made with reference to parasite colonizations and the amount of parasitism shown is therefore representative for the entire area covered by those points.

A study of Table VI shows that the smaller the egg cluster the more heavily parasitized it is. The female Anastatus is unable to oviposit in all the eggs of a cluster, and the percentage of eggs parasitized decreases as the size of the cluster increases. When Anastatus is very abundant and several females are present on a gipsy-moth egg cluster as it is being laid, the parasitism increases, this being especially true in the case of small clusters. It will be noted that during the last two years this difference has increased materially, the small egg clusters being parasitized by over 10 per cent more than were the large ones.

The table shows a steady increase in parasitism by Anastatus until the fall of 1922, when a slight drop occurred. Schedius increased gradually through the fall of 1917, but with few exceptions has not been able to increase in this area since the severe winter of 1917–18.

PERCENTAGE OF GIPSY-MOTH EGGS PARASITIZED BY SCHEDIUS

It appears from the results shown in the foregoing table that Schedius is an unimportant factor as an egg parasite of the gipsy moth in the area represented. The climate of this area has been too severe during the period covered by the collections for this parasite to be of general abundance. During this period, however, Schedius has for several different years been an important egg parasite of the gipsy moth in numerous locations. The fact that it produces several generations each year allows it to increase rapidly under favorable conditions, and within the area under discussion collections of gipsy-moth eggs are often made which show from 10 to 20 per cent of the eggs killed by this parasite.

Schedius seems better suited to the milder climate of southern Massachusetts. For the last five or six years it has been increasing in abundance in

TABLE VI.—*Summary of examinations of gipsy-moth eggs collected around the "observation points"*

Year	Number of points of collection	Number of clusters collected				Eggs parasitized						Total parasitized—		Total parasitism
						By Anastatus—			By Schedius—					
		Large	Medium	Small	Total	Large clusters	Medium clusters	Small clusters	Large clusters	Medium clusters	Small clusters	By Anastatus	By Schedius	
						P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1912–13	77	1,131	1,127	1,102	3,360	0.207	0.19	0.28	0.33	0.50	0.64	0.21	0.43	0.64
1913–14	73	1,068	1,090	1,053	3,211	.718	.87	.23	1.09	1.19	1.54	.85	1.20	2.05
1914–15	69	1,069	1,067	1,048	3,184	.93	1.13	.93	.83	.97	1.16	.99	.93	1.92
1915–16	66	1,037	1,050	1,046	3,133	2.33	2.86	2.91	1.36	1.21	1.57	2.62	1.35	3.97
1916–17	64	921	1,015	1,001	2,937	4.36	5.27	6.46	2.36	2.77	3.31	5.01	2.66	7.67
1917–18	68	792	1,034	981	2,807	6.19	7.69	9.54	2.30	2.83	4.18	7.26	2.78	10.04
1918–19	64	890	913	852	2,655	9.25	10.22	10.75	.11	.09	.21	9.83	.12	9.95
1919–20	49	439	730	731	1,900	9.75	11.16	12.53	.50	.58	.92	10.84	.61	11.45
1920–21	49	667	742	694	2,103	15.57	17.85	19.56	.03	.07	.13	16.98	.06	17.04
1921–22	51	357	708	695	1,760	25.03	28.60	31.20	.09	.12	.23	27.86	.13	27.99
1922–23	49	351	758	333	1,442	17.22	24.25	30.10	.98	.85	1.12	21.94	.93	22.87
1923–24 [a]	17	119	359	104	582	18.51	23.02	30.35	.71	.52	.17	22.18	.55	22.73
1923–24 [a]	60	560	1,403	389	2,352	16.32	20.00	26.78	.33	.32	.21	20.96	.29	21.25

[a] A uniform method of collecting and examining the eggs was followed during the years from 1912 through the spring of 1923. The infestation was so light over much of the area during the fall of 1923 and spring of 1924 that the collections had to be made over a larger area around some of the points. The examination of the eggs from 17 of the points was made in the usual manner. A slightly different method was used for the examination of the eggs from 60 points for 1923–24; the results for the two methods are separately presented.

most of the towns on Cape Cod and along the northwest coast of Buzzard's Bay. Good records of parasitism by Schedius are often obtained from gipsy-moth eggs collected at Martha's Vineyard and from the northeastern part of Rhode Island.

Each fall a survey is made of the towns in the southern part of Massachusetts and collections of masses of gipsy-moth eggs are made from roadside and woodland trees. The percentage of parasitism by Schedius of these collections has increased each year to and through the fall of 1922. The examination of the eggs collected in the fall of 1922 gave the following percentages of parasitism for the towns named: Sutton, 35; Dartmouth, 36; Marion, 37; Mashpee, 18; Harwich, 26; North Harwich, 46; and Woods Hole, 48. Collections of eggs made during the fall of 1923 showed the parasitism to have fallen a few points, but it is still considered good.

SUMMARY

Two egg parasites of the gipsy moth have been established in America. *Schedius kuwanae* Howard, a species which had never been described until the project of gipsy-moth and brown-tail moth investigations was started, was introduced from Japan, its only known habitat. The other species, *Anastatus bifasciatus* Fonsc., came from Japan and from several parts of Europe.

The biology of the two species varies greatly, Schedius having several generations and hibernating as an adult, while Anastatus has but one generation and hibernates as a full-fed larva within the egg of the gipsy moth. Both species are slow-spreading parasites and considerable colonization work remains to be done before they will have the same distribution as the gipsy moth in the Northeastern States.

Anastatus was established by liberating the imported parasites, and its colonization has been continued each year by collecting its host's eggs in New England and separating the parasitized eggs from those containing gipsy-moth larvae. A total of 54,345,193 Anastatus have been colonized.

Schedius was established by breeding a relatively few adults received from Japan through several generations until enough adults of the parasite were obtained to warrant making liberations. It has been colonized in each succeeding year by breeding it through several generations at the laboratory, after having obtained the breeding stock from gipsy-moth eggs collected in New England. A total of 20,799,537 adult Schedius have been colonized.

The data which have been obtained and presented in this bulletin show that Anastatus is now an important egg parasite of the gipsy moth in the area in which it has been generally colonized in New England.

During the most favorable seasons Anastatus should be able to parasitize at least 35 per cent of the gipsy-moth eggs over a considerable portion of the infested area.

It is an important fact that the parasitism by Anastatus of the gipsy-moth eggs increases as the egg clusters decrease in size. There is a tendency for the egg clusters of the gipsy moth to decrease in size after years of great abundance. During a year of great abundance of this parasite, when several Anastatus females are ovipositing in the eggs, even while the egg cluster is being deposited, the average percentage of parasitism may run considerably higher than has yet been obtained.

Schedius is also proving to be an important parasite of the gipsy-moth eggs in the southern part of New England, but apparently it is not able to work to its best advantage in the more severe climates of the northern part of the territory infested by the gipsy moth.

In the southern area during favorable seasons Schedius should parasitize from 30 to 40 per cent of the eggs of the gypsy moth. The fact shown in laboratory experiments that Schedius can reproduce readily in the eggs of several species of insects in addition to those of the gipsy moth may at any time add to the value of this introduction.

NEW NEMATODES FROM NORTH AMERICAN MAMMALS[1]

By EDWARD A. CHAPIN

Zoological Division, Bureau of Animal Industry, United States Department of Agriculture

INTRODUCTION

The nematode worms described in this paper were collected from two species of mammals, the North American buffalo (*Bison bison* L.) and the North American beaver (*Castor Canadensis*), both of which are of considerable economic importance. The bison, once on the verge of extinction, is recovering itself to such an extent that it has been necessary to thin out the herd at Wainright, Alberta, Canada. Thanks are extended to S. Hadwen, of the University of Saskatchewan, for his kindness in submitting the collection of worms for study. The beaver, an important fur-bearing animal of this continent, has received little attention from parasitologists. Morgan[2] noted the presence of strongyles in the colon and cecum but did not give a description.

DESCRIPTION

NEMATODES FROM BISON

Dictyocaulus hadweni n. sp.

MALE: 52 mm. greatest diameter, 518 μ at about the middle, cuticle thin and smooth, without transverse striations. Head rounded, 89 μ in diameter, amphids conspicuous, other papillae not evident, tube leading from amphid reaching the nerve ring. Nerve ring about 311 μ, excretory pore about 620 μ, behind anterior extremity. Esophagus 1.48 mm. long; its width at the anterior extremity, excretory pore, and just before the intestinal valve, 89 μ, 104 μ, and 178 μ, respectively. Caudal bursa moderate in size, about 400 μ in diameter, nearly circular. Dorsal ray divided completely to base, abruptly trilobed at apex, the inner lobe slightly longer and thinner than the other two. Externo-dorsal ray simple, slender, not quite as long as either branch of dorsal ray. Postero-lateral and medio-lateral rays completely fused, forming a single slender ray slightly longer than the externo-lateral which is of the same thickness. Ventral rays separate to base or nearly so, ventro-ventral but about half as long as latero-ventral. Spicules stout, subacute at apices, each with a semicircular transparent wing in apical third, from 260 to 300 μ in length. Gubernaculum oval, feebly chitinized, about 85 μ long (fig. 1).

FEMALE: Length about 60 mm., greatest diameter about 640 μ, at the middle of the length. Pharynx about 100 μ deep, very narrow; esophagus 1.3 mm. long, its greatest diameter 192 μ, just before the intestinal valve. Nerve ring 340 μ. Excretory pore 475 μ behind the anterior extremity. Vulva transverse, lips prominent, situated at about the posterior third of the body length. Uteri divergent, the anterior branch reaching nearly to the esophagus. Anus 163 μ in front of the posterior extremity. Tail acute, conical. Eggs 80 by 35 μ, embryonated in uteri.

HABITAT: In lungs of *Bison bison*.

LOCALITY: Canada, Wainright, Alberta, February, 1923; S. Hadwen, collector.

TYPE: United States National Museum, Helminthological Collections, No. 26100; paratypes Nos. 25954 and 25956.

Compared with *D. filaria* (Rud.), the above species differs in the more abrupt termination of the branches of the dorsal ray, in the complete fusion of the postero-lateral and medio-lateral rays and in the longer spicules.

Besides the type material, there are two lots of worms in the helminthological collections of the United States National Museum from *Alce americanus* (No. 18832) and *Cervus canadensis* (No. 19456), respectively. While there are some slight differences between these and the specimens from the type host, they can hardly be considered as specific and they appear to be of the same species.

Ostertagia bisonis, n. sp

MALE: Length 6.2 mm., greatest width 80 μ, just in front of the bursa.

[1] Received for publication June 30, 1924; issued June, 1925.

[2] MORGAN, L. H. THE AMERICAN BEAVER AND HIS WORKS. 330 p., illus. Philadelphia. 1868.

Diameter of head 19 μ; diameter of body at nerve ring 45 μ, at base of esophagus 60 μ. Esophagus 620 μ in length; nerve ring 207 μ behind the anterior extremity. Excretory pore and cervical papillae at same level, 265 μ behind anterior end. Bursa similar in shape to that of *O. trifurcata* Rans., 178 μ long in lateral view, prebursal papillae short and inconspicuous, 16 μ in front of the origin of the ventral rays. Dorsal ray slender, 32 μ long from origin to bifurcation, each arm 36 μ long with a very short external branch near the tip. Externo-dorsal ray ends near the margin of the bursal membrane close to the limit of the thick dorsal lobe. Dorsal lobe 80 μ long, 48 μ wide and 45 μ thick, granular, not transparent as the bursal membrane. Tip of medio-lateral ray only half as far from that of postero-lateral as from that of externo-lateral. Latero-ventral ray bent so as to bring its tip in close proximity with that of the ventro-ventral. Spicules from 130 to 140 μ long, similar in length but differing in conformation. The right spicule ends in a short corkscrewlike hook, while the tip of the left is acute and slightly curved. On the ventral aspect of each, at about 42 μ before the posterior extremity there is a small boss, directed toward the median line of the worm. At the same level, each spicule gives forth two thin, nearly transparent, acute processes, directed posteriorly, each process about 29 μ long. Gubernaculum absent.

FEMALE: Length 6.75 mm., maximum thickness 89 μ, in vicinity of the vulva. Head 22 μ in diameter, esophagus 670 μ long; nerve ring 215 μ behind anterior end. Excretory pore and cervical papillae at same level, 280 μ behind anterior end. Vulva a transverse crescentic slit, nude, 1.17 mm. in front of posterior extremity. Anus 144 μ in front of tip of tail. Tail gradually attenuated, rounded at tip. Combined length of oviejectors about 450 μ; sphincters 45 μ long by 64 μ in diameter. Eggs ovate, 64 to 77 μ long by 45 to 48 μ wide.

HABITAT: In fourth stomach and duodenum of *Bison bison*.

LOCALITY: Canada; Wainright, Alberta, January 28, 1923; S. Hadwen, collector.

TYPE: United States National Museum, Helminthological Collections, No. 26101; paratypes Nos. 25960, 26103.

This species is most closely related to *O. trifurcata* Rans., and in his key (Ransom)[1] it would run out at that species. The spicules are, however, a trifle smaller in the present species, and are of a different conformation.

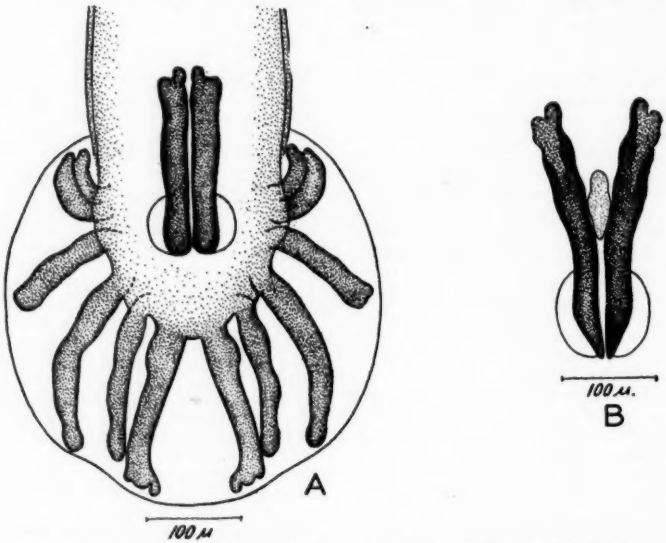

FIG. 1.—*Dictyocaulus hadweni*, n. sp. *A*, bursa of male; *B*, spicules and gubernaculum

[1] RANSOM, B. H. THE NEMATODES PARASITIC IN THE ALIMENTARY TRACT OF CATTLE, SHEEP, AND OTHER RUMINANTS. U. S. Dept. Agr., Bur. Anim. Indus. Bul. 127, 132 p., illus. 1911.

NEMATODES FROM BEAVER

Travassosius americanus, n. sp.

MALE: 11 mm. long, slender, 96 μ in diameter at the level of the esophageintestinal valve, diameter increases evenly to 116 μ at a point just in front of the prebursal papillae. Head small, 30 μ in diameter, buccal capsule absent, esophagus 575 μ long; its greatest diameter is 65 μ near the posterior end. Nerve ring surrounds esophagus at a plane 260 μ behind the anterior end. The excretory pore is about 345 μ from the head. The cervical papillae are large, conical, and prominent, about 50 μ behind the excretory pore. The prebursal papillae are lateral, 50 μ in front of the anterior margin of the bursa. The bursa is in most respects similar to that of *T. rufus* Khalil.[4] The most conspicuous difference is in the formation of the dorsal ray, which bifurcates at a point 56 μ from the base of the ray and produces two branches, each 16 μ neither of which bifurcates at the extremity. The spicules are two, and similar, from 148 to 152 μ long. Gubernaculum is absent.

FEMALE: 12 mm. long; diameter of head 30 μ, greatest diameter 128 μ, near vulva. Esophagus about 600 μ long, nerve ring 280 μ behind its anterior end. Excretory pore 430 μ, cervical papillae 460 μ from anterior end. Vulva about 3 mm. from the tip of the tail. Tail slender, slightly recurved at its tip, anus 240 μ from the tip. The length of the combined portions of the ovejectors, including the sphincter muscles is about 630 μ; each sphincter alone measures 45 μ long by 60 μ in diameter. The eggs are oval, thin shelled, from 82 to 90 μ in length by 43 to 50 μ in width.

HABITAT: In stomach of *Castor canadensis*, National Zoological Park, Washington, D. C., January 23, 1924; E. A. Chapin collector.

TYPE: United States National Museum, Helminthological Collections, No. 25966, paratypes No. 26107. Paratypes also deposited in the British Museum (Natural History).

This species is very closely related to *T. rufus* Khalil, the type of the genus. The spicules are smaller in the present species and are somewhat different in conformation.

Castorstrongylus n. gen.

Strongylidae, Strongylinae, Cylicostomeae. Medium-sized worms, sexes of approximately the same size. Buccal capsule large, heavily walled, without teeth at base. External corona of fimbriated elements, internal corona of short, stout peglike elements. Cervical papillae and excretory pore a short distance apart, both behind the nerve ring. Bursa of male moderate. Ventral rays close together and parallel, externo-dorsal arising free of the trunk of the dorsal, dorsal twice bifurcated. Vulva near anus, uteri directed anteriorly, convergent.

HABITAT: In colon of a rodent.

TYPE AND ONLY KNOWN SPECIES: *Castorstrongylus castoris* n. sp.

The type species has the habitus of a true Strongylus while the bursal and other characters usually chosen as of tribal importance place it in the neighborhood of the cylicostomes.

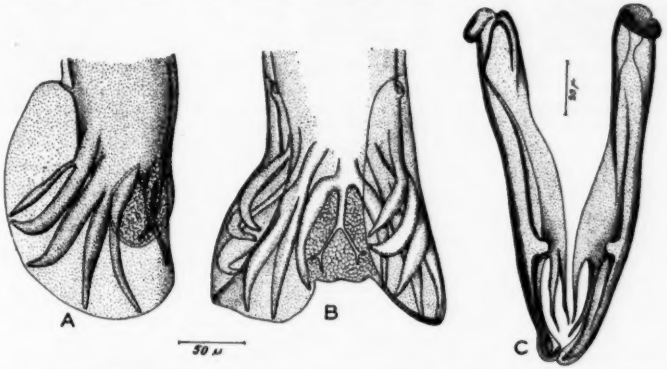

FIG. 2.—*Ostertagia bisonis*, n. sp. *A*, bursa of male from side; *B*, same, ventral view; *C*, spicules

[4] KHALIL, M. TRAVASSOSIUS RUFUS, GEN. ET SP. N.: A NEMATODE (TRICHOSTRONGYLIDAE) PARASITIC IN THE STOMACH OF THE NORWEGIAN BEAVER, Ann. and Mag. Nat. Hist., 10: 281–289, illus. 1922.

Castorstrongylus castoris, n. sp.

SYNONYMS: *Sclerostoma* sp. Morgan, 1868;[5] *Strongylus* sp. Hall, 1916.[6]

MALE: 11 mm. in length; greatest diameter 645 μ, at about the middle of the length. Mouth opening anterior, surrounded by a prominent collar 285 μ in diameter by 60 μ in height. Circumoral papillae situated on collar, submedian papillae prominent, lateral papillae obsolete, amphids distinct. Buccal capsule large, walls 25 μ thick, internal diameter (dorso-ventral) 240 μ, depth 195 μ, dorsal gutter distinct, toward base of capsule lying in a thickened ridge. External corona composed of 24 elements, each element fimbriated at its anterior border, num-

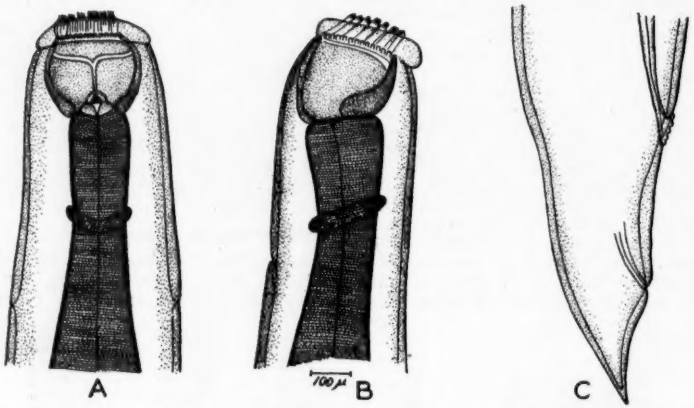

FIG. 3.—*Castorstrongylus castoris*, n. sp. *A*, anterior end of male, ventral view; *B*, same, lateral view, *C*, posterior end of female

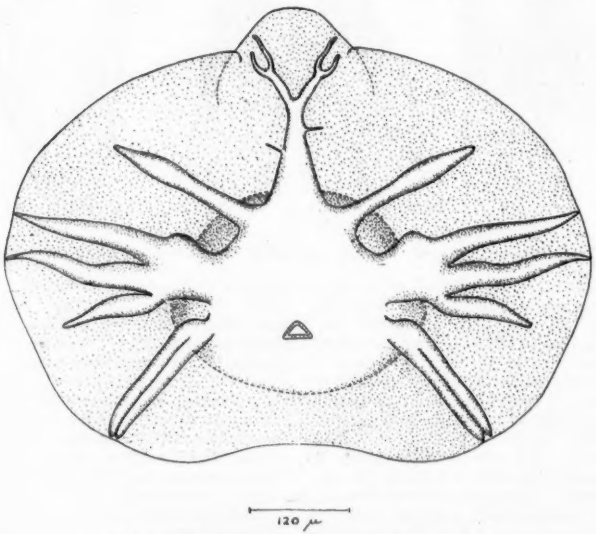

FIG. 4.—*Castorstrongylus castoris*, n. sp. Bursa, male

[5] MORGAN, L. H. THE AMERICAN BEAVER AND HIS WORKS. 330 p., illus. Philadelphia. 1868.

[6] HALL, M. C. NEMATODE PARASITES OF MAMMALS OF THE ORDERS RODENTIA, LAGOMORPHA, AND HYRACOIDEA. Proc. U. S. Nat. Mus. 50: 1-258, illus. 1916.

ber of divisions varying from 5 to 7. Internal corona composed of 48 peglike elements, each peg about 8 μ long, cylindrical, rounded at apex. Internal corona situated within the collar, about 30 μ behind the anterior margin. Esophagus 1.2 mm. long, clavate, greatest diameter 250 μ near the intestinal valve, diameter at buccal capsule 195 μ, diameter at nerve ring 165 μ. Nerve ring surrounding esophagus at its anterior fourth. Cervical papillae small, situated just anterior to the middle of the esophagus, excretory pore just behind cervical papillae. Bursa transversely oval, dorsal lobe trapezoidal, dorsal trunk bifurcated, at about half its length, each fork bifurcated near tip. On each side of main trunk there is an exceedingly short and slender branch. Externo-dorsal ray moderately thick, parallel, originating halfway between the main trunks of the dorsal and lateral rays, ending some distance from the margin of the bursa. Lateral rays stout, postero-lateral and medio-lateral; not close together but subparallel; tips at margin of bursa, end of externo-lateral remote from the bursal margin; ventral rays similar in size to the laterals, close together, parallel, ending on bursal margin. Spicules 1.4 to 1.5 mm. long, slender, somewhat twisted. Gubernaculum wanting (fig. 4).

FEMALE: 12 mm. in length, greatest diameter 645 μ at about middle of length. Mouth collar slightly lower that that of male but of the same diameter. Dorso-ventral diameter of buccal capsule 240 μ, equal to the greatest depth. External and internal coronae similar to those of male. Esophagus 1.10 mm. long, 300 μ in diameter just before the intestinal valve, nerve ring at anterior fourth of esophagus, excretory pore at the level of the nerve ring, cervical papillae 255 μ behind the excretory pore. Tail conical, slender; anus 315 μ in front of extreme tip, vulva 375 μ in front of anus. Eggs 83 to 92 μ long by 51 to 54 μ wide, up to the eight-celled stage in uterus.

HABITAT: In colon of *Castor canadensis*, National Zoological Park, Washington, D. C.; January 22, 1924; E. A. Chapin, collector.

TYPE: United States National Museum Helminthological Collections, No. 25967; paratypes No. 26104. Paratypes also deposited in the British Museum (Natural History).

FURTHER INVESTIGATIONS OF INFECTIOUS EQUINE ANEMIA IN NEVADA[1]

By LEWIS H. WRIGHT

Nevada Agricultural Experiment Station[2]

INTRODUCTION

Infectious equine anemia was first reported in Nevada by Mack (*5*, *6*, *7*, *8*), in 1909; (*9*)[3] in 1909. He made extensive observations on the pathology, bacteriology, and symptomatology of the disease, but with one possible exception was unable to transmit it to other horses, and so failed to arrive at any positive conclusion as to its etiology. All of Mack's material came from one portion of the State, the region of the south fork of the Humboldt River in Elko County, where the disease had been prevalent and had caused extensive losses periodically for a number of years.

Since this first report the disease has been found and studied around Fallon in Churchill County, near Washoe in Washoe County, and along the north fork of the Humboldt River. There have been reports of its having occurred around Yerington, Pahrump, Lovelock, and Battle Mountain, but these reports have not been confirmed.

It is especially interesting to note that all of the infected areas are a considerable distance from one another, and, as far as can be ascertained, there has been little or no interchange of animals among them. In fact, many of the infected animals had never left the ranch where they were raised.

From 1909 until 1918 the disease was apparently quiescent and caused very little loss. In fact, material for experimental purposes was at times unprocurable and very little work was done during this period. In September, 1917, material was procured from Antelope Valley and some experiments were undertaken. This outbreak subsided, however, and the experimental virus was lost, owing to its lack of pathogenicity.

In September, 1918, material was obtained from natural field cases at Fallon. Most of this report is based on experimental work done with virus from this source.

In this report it is intended to touch some phases of the disease not solved by Mack, such as transmissibility, differential diagnosis, etc. Mack's (*6*, *7*, *8*, *9*) observations on the pathology and symptomatology of the disease are sufficiently complete to need little repetition here. If the form of anemia with which Mack worked is identical with that reported from other States and foreign countries, the thing that stands out conspicuously in his experiments is the great difficulty which he encountered in transmitting the disease. This may have been due to the fact that he inoculated only animals in districts where the disease was prevalent. In other words, he may have used no really susceptible animals. His fear of introducing the disease in new areas caused him to refrain from inoculation experiments at Reno.

If the disease upon which the present investigations are based is the form of anemia usually found, this work will present very little that is wholly new. However, this report may establish some new facts concerning the local disease, especially its transmissibility, and may add others to show that it is the same disease encountered elsewhere.

EXPERIMENTAL DATA

The observations of the writer agree with those of Mack (*6*) in this, that there are three types of the disease, namely, acute, subacute, and chronic. Although distinct, the three types are separated by no hard and fast line, and a case that is thought to be acute may develop into subacute or chronic, or vice versa. Ranchers have reported some acute fatal cases, but there is considerable evidence to support the belief that the cause of death in these cases was not infectious anemia. No opportunity was offered to check up on these cases by animal inoculation.

In these later observations the blood examinations were made in the chronic field cases to exclude intestinal para-

[1] Received for publication June 11, 1924; issued June, 1925.

[2] Resigned June 1, 1920.

[3] Reference is made by number (italic) to "Literature cited," p. 692.

sites, the differentiation being based partly on the presence or absence of an eosinophilia. This method proved sufficiently satisfactory until a group of eight colts, 2 to 4 years of age, was encountered. These colts had been in and near places where infectious equine anemia was known to be present. Physical examination showed the usual symptoms of this disease, which are similar to strongylosis, some of the animals running a temperature of 105° F. or more. The high temperature and the absence of an eosinophilia pointed very strongly to infectious equine anemia. The disease was diagnosed as such, and since the animal had been ailing for some time, was considered of the chronic type.

The animals were brought to the laboratory for further study and treatment. Repeated blood examinations over a period of weeks demonstrated the usual number of eosinophiles and there was no appreciable lymphocytosis, the differential count being well within the usual boundaries for normal animals. A pronounced anemia was noted in some of the colts, the red cells being as low as 3,888,000 per c. mm. Eventually, all the animals died or were killed when death was imminent.

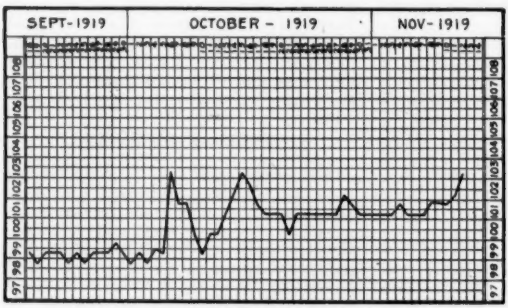

FIG. 1.—Temperature record of animal No. 2965

With one exception, all showed extreme infestations with Strongylus and Cylicostomata; this one exception having 1,000 Gastrophillus in the pylorus. Repeated blood inoculations on many susceptible animals failed to reproduce the disease and for this reason infectious equine anemia can positively be excluded. In this connection it might be said that in one horse which consistently showed from 15 to 17 per cent of eosinophiles, but few parasites of any kind were present at autopsy. It can safely be stated that the presence or absence of an eosinophilia is of little or no aid in making a diagnosis of infectious equine anemia, the only positive diagnosis possible at present being that secured by reproduction of the disease in an animal by inoculation.

For the inoculation great care was taken to use only healthy animals and to see that there was no chance of accidental infection.

No. 2965.—On September 18, black gelding 12 years of age, in good flesh and spirits, weighting 1,185 lbs., was given intravenously 480 c. c. of whole blood from No. 2597, a chronic experimental case produced by Berkefeld-filtered blood from a typical field case; September 25, given intravenously 150 c. c. of whole blood from No. 2597; October 9, given intravenously 200 c. c. of whole blood from 2597; November 1, weight, 1,055 lbs.; November 7, weight 990 lbs.; edema of abdomen; very weak but appetite very good; November 13, unable to stand; continued loss of weight; November 14, animal died. During the illness this animal showed the typical symptoms of infectious equine anemia. Blood examination on November 1 showed a slight decrease in red cells as compared with a count made on the day of the first inoculation. Figure 1 gives the temperature record of this animal.

No. 2563.—On October 22, middle-aged gelding in good physical condition weighing 940 lbs., was given subcutaneously 100 c. c. of defibrinated blood from No. 2250, a typical acute field case. The first symptoms of the disease were shown on November 5. The animal gradually lost weight, became weak, the mucous membranes of the eyes and the nose took on a yellowish-red tinge and on November 13 its weight was 840 lbs. On November 14 there was some hemorrhage from the right nostril. On November 15 the animal was unable to get up, there was some edema of the legs, and hemorrhage beneath the nasal mucosa. The animal died November 17. There had been a gradual fall in the number of red cells and in the percentage of hemoglobin (fig. 2).

No. 2684.—On March 6, healthy gelding 8 years of age, weighing 1,015 lbs., was given, partly subcutanously and partly intravenously, 350 c. c. of a solution made by taking 250 c. c. of whole clotted blood from No. 2561, a typical field case, and shaking it with physiological salt solution and straining out the clumps of fibrin. The first symptoms were noted on March 18 when the animal appeared dejected and listless. He gradually grew worse and on April 6 there was edema of the abdomen and prepuce, and the mucous membranes of the eyes and nose were reddish yellow. On April 11 the weight was 910 lbs. On April 15 he was very weak, dejected, and passed bloody urine. Death occurred on April 16. The hemoglobin and red

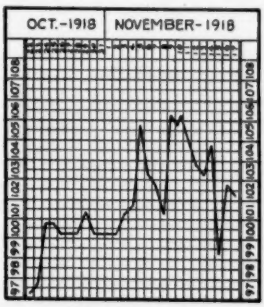

FIG. 2.—Temperature record of animal No. 2563

cells gradually decreased and the lymphocytes slowly increased during the illness of the animal (fig. 3).

No. 2932.—On August 25, aged healthy gelding, weighing 1,195 lbs., was given 50 c. c. of whole blood, intravenously, from experimental case No. 2796. On September 12, 200 c. c., and on September 25, 400 c. c. more were given. The first symptoms with edema were noticed on October 6. The animal gradually became worse with loss of flesh and spirits and continued ill until early in January, when he apparently recovered and remained well until he was killed on February 17, being apparently healthy at this time. On October 9 the hemoglobin was 60 per cent, the red cells 5,834,000 and the lymphocytes 42.2 per cent. This condition gradually improved and was normal at the death of the animal (fig. 4).

No. 2283.—On August 21, a middle-aged healthy gelding weighing 1,070 lbs., was given intravenously 30 c. c. of defibrinated blood from a typical subacute case. The first symptoms—weakness, loss of flesh and spirits, edema of the prepuce and pale yellowish mucous membranes—were noticed in about six weeks. This condition gradually became worse with development of edema of the legs and abdomen, nasal hemorrhage and polyuria. The blood drawn from the veins was thin, did not clot readily, and the corpuscular volume was about one-fifth the total volume. The serum was tinged with yellow. The general condition of the animal gradually improved and he was in fairly good form during the latter part of October. Some severe exercise at this time, however, was apparently too much for his weakened resistance; he rapidly became worse and died on November 4. At the time of death the hemoglobin

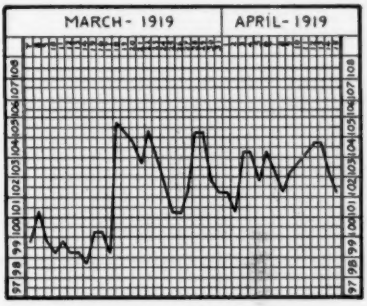

FIG. 3.—Temperature record of animal No. 2684

was 40 per cent and the red cells 3,936,000 (fig. 5).

No. 2801.—On June 9, a middle-aged healthy mare, weighing 850 lbs., was given intravenously 450 c. c. of whole blood from No. 2597. On June 6 and July 3, respectively, 400 c. c. of blood were injected. On August 13 and September 12, respectively, 500 c. c. of blood were injected. The first symptoms were noticed on September 13, a brownish-red nasal discharge, weakness, and general indisposition. The animal gradually became worse and died on September 29. The hemoglobin and red cells decreased slightly during the illness of the animal (fig. 6).

No. 2586.—On November 12, a healthy mare 10 years of age, weighing 939 lbs., was given intravenously 60 c. c. of mixed defibrinated blood from Nos. 2316, 2317, and 2318, three suspected field cases. On November 25, she was given 30 c. c. more of defibrinated blood from No. 2317 and No. 2318. The first symptoms were noticed two weeks after this last injection, and the animal died on December 12 (fig. 7).

No. 2796.—On June 4, a healthy gelding 10 years of age, weighing 1,085 lbs., was given intravenously 800 c. c.

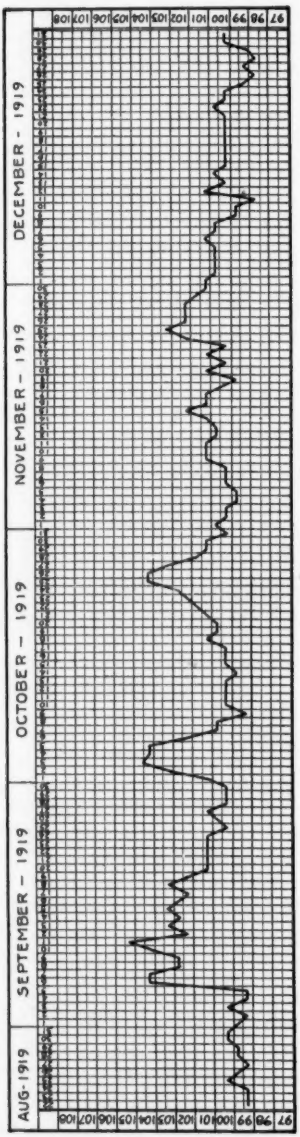

FIG. 4.—Temperature record of animal No. 2932

of blood serum from No. 2913, a typical field case. On June 19 this animal was given 500 c. c. more of serum from the same field case. The first symptoms of disease were noticed on June 24. The animal slowly grew worse until about August 15 when he became very ill and remained so until September 1. He gradually improved and remained well from about September 12 until February 19, when he was killed. During the animal's illness the red cells decreased, the hemoglobin was below normal and the lymphocytes were above normal. Later they came back to normal and remained so until the animal was killed. Figure 8 shows the temperature record of this horse. From June 4 until July 27, and from September 30 until he was destroyed, the temperature was normal.

No. 2676.—On February 19, a healthy gelding 12 years of age was given intravenously 750 c. c. of whole blood from No. 2597, an experimental case produced from a typical field case by Berkefeld filtrate. The first symptoms were noted on February 27. Later the mucous membranes became pale and tinged with yellow and there was some serous nasal discharge. The condition of the animal gradually became worse and he died on March 23. The red cells and hemoglobin showed about a 25 per cent reduction during the illness of the animal (fig. 9).

Since the disease was found to be transmissible to susceptible animals by inoculation of whole and defibrinated blood, it was desired to see if it could be transmitted by the injection of Berkefeld-filtered material. Accordingly, blood was drawn from some of the field and experimental cases, Berkefeld-filtered, and injected into susceptible animals. Before use the filters were tested with known cultures of bacteria to check their efficiency.

No. 2008.—On November 2 a healthy mare 12 years of age, weighing 925 lbs., was given intravenously 10 c. c. of Berkefeld-filtered blood serum from experimental case No. 1948. This animal remained healthy until May 24, when many petechiae were noted in the nose, with some hemorrhage. On June 3 she was definitely ill. She gradually became worse, however, developing reddish-yellow membranes, serous nasal discharge, edema of the legs and abdomen, and loss of weight, weighing 748 lbs. She died on July 14. Very little change was noted on blood examination until the late stages of the disease, when there was about a 20 per cent reduction in the hemoglobin and red cells (fig. 10).

No. 3036.—On January 28 a healthy mare 14 years of age was given intra-

venously 100 c. c. of Berkefeld-filtered blood serum from No. 2597, an experimental case produced with filtrate. The first symptoms were noted on February 20. The progress of the disease was very rapid, and the animal died on February 22 (fig. 11).

No. 2597.—On November 10 a healthy gelding 2 years of age, weighing 650 lbs., was given 30 c. c. of Berkefeld-filtrate from experimental case No. 2563. On November 20 he was given intravenously 30 c. c. of filtrate of blood and splenic emulsion and 40 c. c. more on the following day. On January 16 he was quite ill and remained so for some time, gradually recovering and being apparently well by February 15, when he weighed 732 lbs. About March 18 he had a relapse and was very ill for a week. His weight fell to 573 lbs. At this time he was so ill that he was expected to die, but he gradually recovered and was apparently well by the middle of April. From this time until he was killed on February 26, nearly a year later, he showed no departure from the normal. During this time, however, he was an active carrier of the virus, many subinoculations being made from him, some of which are reported here. Figure 12 shows his temperature record. During the break in his temperature record, and from April 11 until his death, the temperature was normal. During the illness of this animal the hemoglobin and red cells were decreased about 20 per cent and the lymphocytes went as high as 54.4 per cent.

As a check on the diagnosis, and in order to eliminate acute bacterial diseases, blood was taken at nearly every autopsy for subcutaneous and intraperitoneal inoculations on rabbits and guinea pigs. From time to time emulsions from the liver, spleen, and lymph glands were also injected. At no time was there any evidence of a reaction in one of these animals.

Attempts were made to reproduce the disease in animals other than horses, but all of these failed. Common house mice, rabbits, guinea pigs, calves, sheep, and pigs were injected with blood and kept under careful observation for periods varying from weeks to several months, all with negative results.

DISCUSSION

This report can add little to the autopsy findings reported by Mack (*6*), with the exception of those in the long bones. Many writers have considered that the findings in the bone marrow are characteristic of the disease. In a previous paper the writer (*18*) has quite conclusively shown that these changes are not characteristic and may even be greater in other diseases than in infectious equine anemia.

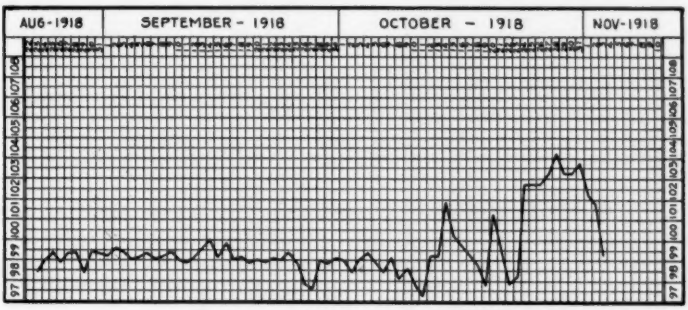

FIG. 5.—Temperature record of animal No. 2283

At all autopsies cultures were made on neutral plain agar and neutral plain broth. At autopsies and at times during the acute illness of the various cases cultures were made on special media. These media included normal rabbit blood agar; 10 per cent horse serum, 2 per cent agar and physiological saline; 15 per cent horse serum and water; 5 per cent horse serum and water; 15 per cent horse serum and physiological saline; 5 per cent horse serum and physiological saline; 25 per cent horse serum and water; 12 per cent horse serum and water; 25 per cent horse serum and physiological saline; 12 per cent horse serum and physiological saline. Some of these cultures were oiled in order to secure anerobic conditions, a piece of rabbit testicle being added in some cases and a piece of rabbit kidney in others. All cultures were incubated

at 37.5° C. for varying periods of time, some as long as two months. At no time was there any growth that could be considered anything but contamination from outside sources. These results do not agree with those of Miyagawa, Taniguchi, Nagao, and

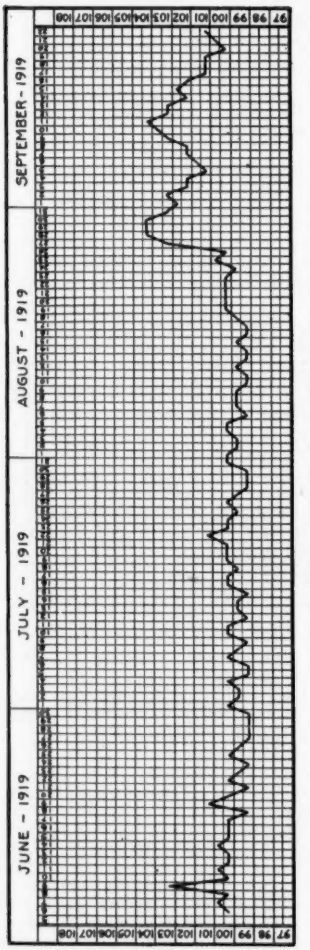

FIG. 6.—Temperature record of animal No. 2801

Takemoto (*11*), who were working with what is supposed to be the same disease in Japan. These investigators claim that spirochaetes can be observed in direct smears from the blood stained with Giemsa's stain. Almost without exception the blood smears made by the writer have been so stained, but at no time has anything resembling a spirochaete been seen in them. This statement is based on hundreds of examinations made over a period of years. At various times fluids from the edematous areas also was smeared and stained for spirochaetes by the silver and India-ink methods, but the results obtained were negative.

One thing that stands out conspicuously in the severest cases of anemia is the lack of erythroblasts. These are seldom encountered and then only in small numbers. Apparently the regenerative powers of the animals are unable to cope with the loss of red blood cells. Perhaps this lack of regeneration or red cells is one of the causes of the acuteness of the disease, although the chronic cases are the ones that show the most pronounced anemia, the acute cases in many instances showing little or no loss of red cells.

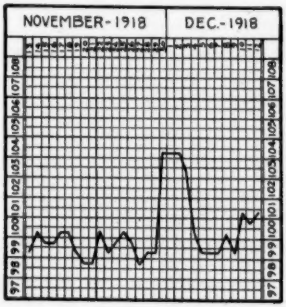

FIG. 7.—Temperature record of animal No. 2586

This lack of ability to regenerate red cells may be one of the reasons why there are no marked changes in the bone marrow. One would not expect to find extensive marrow changes unless there was active blood regeneration.

There seems to be a greater loss of red cells in the field cases than in the experimental ones. This may be accounted for by the overwhelming quantities of blood injected into the latter and the consequent acuteness of the disease produced. The field cases as a whole are apparently less acute than the experimental ones.

During the routine examination of the stained smears there have been observed the so-called intracorpuscular bodies, described by Mack (*10*). What relation these have to the disease in question is as yet unsettled. In these examinations they have been found present in many cases. They have also been found in normal horses

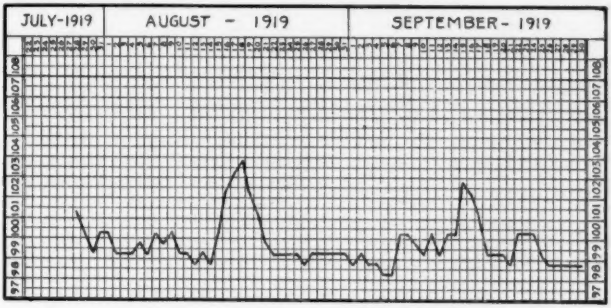

FIG. 8.—Temperature record of animal No. 2796

and in horses affected with other diseases. They are especially numerous in the blood of horses used for the production of hemorrhagic septicemia antiserum. Later developments may show that they are peculiar to this disease or that they are some form of antibody or immune body. Their presence in greater numbers in the blood of the hyperimmune horses would tend to confirm this. In this connection further observations will be of value.

DIAGNOSIS

Too much emphasis can not be laid on the fact that the only positive differential diagnosis of infectious anemia is by the reproduction of it in a susceptible animal. Sometimes, however, a fairly accurate diagnosis can be made from a physical examination, including a blood count. If the case can be observed for a few days in order to get a temperature curve this is also a great help. From the writer's observations the two conditions most likely to be confused with the disease are parasitisms and nonspecific secondary anemias. The differentiation from parasitisms has been mentioned previously. That of nonspecific anemias requires considerable care and judgment but is apparently less difficult, for as a rule, some contributing factor can be found.

Usually the autopsy lesions are of some help in diagnosing the disease. In general, there is an enlargement of the spleen, a peculiar brownish, granular condition of the liver, the latter being very friable, and in many cases there are extensive epicardial and endocardial hemorrhages.

TRANSMISSION

Little work has been done here on the methods by which the disease is spread. Carré and Vallée (*1, 2, 3, 4*) and others believe that it is spread by urine, feces, and other body discharges, contaminating the food and drink of healthy horses. Scott (*12, 13, 14, 15, 16, 17*) has apparently proved that flies spread the disease. From the investigations made by the writer it seems highly probable that flies are an important factor in its dissemination. When material was available, a healthy horse was put with the sick; they ate from the same manger, drank from the same tub, and were kept in intimate association with one another. This experiment was repeated several times,

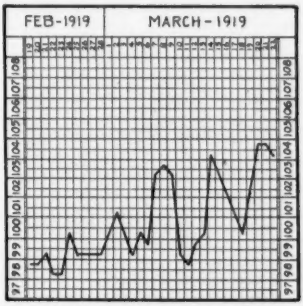

FIG. 9.—Temperature record of animal No. 2676

so that there is little chance that an animal which was naturally resistant would be used in every instance. One horse was kept for over 16 months in continual contact with the sick ones. None of the experimental animals showed any evidence of having contracted the disease. It is of interest to note that there were few, if any, biting flies present where these animals were kept.

One should not overlook the important fact that the disease is most prevalent in the season of the year when biting and sucking flies are most abundant, namely, the late summer and fall. If one can take a small quantity

of infected blood in a syringe and transfer it to an animal and thus reproduce the disease it seems highly probable that a biting fly can achieve the same result. Occasionally droplets of blood have been seen on the skin of a horse, caused by the bite of a fly. There is apparently some relation also between the number of cases of the disease in a given year and the number of flies, the more flies there are the more cases appear.

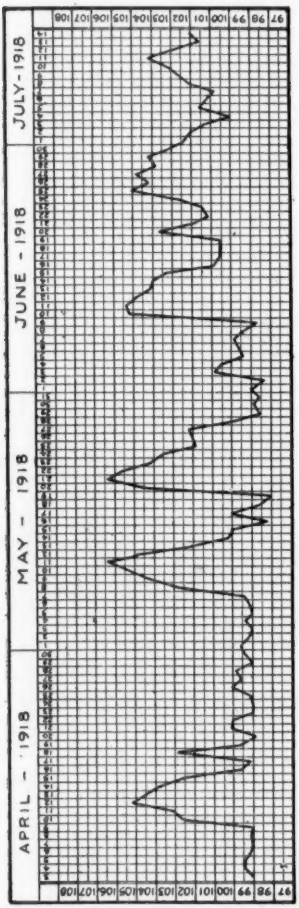

FIG. 10.—Temperature record of animal No. 2008

CONTROL

No satisfactory treatment for the disease is known. Many investigators have tried various methods with no uniform success. Some have recommended the use of such drugs as sodium cacodylate, atoxyl, trypan-blue, trypan-red, quinine, tartar emetic and various other compounds. Under critical observations, however, all of these have failed. Nearly all of the known methods of treatment have been tried by the writer both in the field and in experimental cases. At no time has anything resembling a cure been found. Some known cases have lived for some time and been apparently well, but inoculations from them have shown that they were still carriers of the virus. In the light of our present knowledge of the disease, there might even be danger in attempting to cure it, since cases supposedly cured might become sources of infection to other animals. What is probably necessary is the immediate distruction of all suspected cases. Definitely diagnosing the disease by animal inoculation is a long and expensive process and is practically out of the question in routine work. The control of biting flies, clean sanitary premises, and good hygienic surroundings for the horses are probably the greatest factors in the control of the disease.

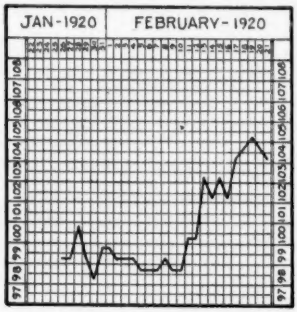

FIG. 11.—Temperature record of animal No. 3036

CONCLUSIONS

There exists in Nevada a disease among horses which is apparently identical with that known in other States and countries as infectious equine anemia, swamp fever, infectious anemia, etc. The disease is characterized clinically by irregularly remittant fever, rapid emaciation, marked loss of energy, depletion of red blood cells in most cases, edema, usually bloody nasal discharge, and eventually death. The mortality is nearly 100 per cent, real recovery rarely, if ever, taking place. The disease is transmissible to other horses by the injection of infected blood or splenic emulsion, the period of incubation being from about two weeks to several

months. The etiological factor is apparently ultramicroscopic, since the disease can be reproduced by the injection of Berkefeld filtrates, and is not recognizable by ordinary staining methods in smears from the blood, tissues or exudates and transudates. The natural mode of transmission is not known, but is most likely through the bites of insects. Methods of treatment thus far used have proved unsuccessful, killing the infected animals being necessary to prevent spread of the disease. A positive diagnosis can only be secured by animal inoculation. Animals other than equines are not susceptible to the disease.

LITERATURE CITED

(1) CARRÉ, H., and VALLÉE, H.
1904. SUR L'ANÉMIE INFECTIEUSE DU CHEVAL. Compt. Rend. Acad. Sci. [Paris] 139: 1239-1241.

(2) ——— and VALLÉE, H.
1905. RAPPORT SUR L'ANÉMIE INFECTIEUSE DU CHEVAL. Bul. Mens. Off. Renseig. Agr. [Paris] 4: 1075-1077.

(3) ——— and VALLÉE, H.
1906-07. RECHERCHES CLINIQUES ET EXPÉRIMENTALES SUR L'ANÉMIE PERNICIEUSE DU CHEVAL (TYPHO-ANÉMIE INFECTIEUSE). Rev. Gén. Méd. Vét 8: 593-608, illus., 1906; 9: 113-124, illus., 1907.

(4) ——— and VALLÉE, H.
1916. SUR L'ÉTIOLOGIE DE L'ANÉMIE INFECTIEUSE DU CHEVAL. Rec. Méd. Vét. 92: 193-199.

(5) MACK, W. B.
1909. EQUINE ANEMIA. Nev. Agr. Exp. Sta. Bul. 72: 46-47.

(6) ———
1909. EQUINE ANEMIA. AN ACCOUNT OF A RECENT INQUIRY INTO THE NATURE AND CAUSE OF AN OBSCURE AND FATAL DISEASE AMONG HORSES IN EASTERN NEVADA. Nev. Agr. Exp. Sta. Bul. 68, 96 p., illus.

(7) ———
1909. A STUDY OF A SERIOUS ANEMIC DISEASE AMONG HORSES. Amer. Vet. Rev. 36: 222-247, illus.

(8) ———
1910. ANEMIA IN HORSES. Nev. Agr. Exp. Sta. Bul. (1908) 66: 65-68.

(9) ———
1910. A FATAL ANAEMIC DISEASE AMONG HORSES. Proc. Amer. Vet. Med. Assoc. (1909) 46: 307-321, illus.

(10) ———
1911. INTRACELLULAR BODIES ASSOCIATED WITH EQUINE ANEMIA. Proc. Amer. Vet. Med. Assoc. 48: 378-382, illus.

(11) MIYAGAWA, Y., and others.
[1918]. [ON THE MICROORGANISM CAUSING INFECTIOUS ANEMIA OF THE HORSE AND ITS PURE CULTIVATION.] Saikingaku Zasshi, No. 267. [Japanese original not seen. Abstract in Jour. Amer. Vet. Med. Assoc. (n. s. 9) 56: 642-649, 1920.]

(12) SCOTT, J. W.
1913-15. SWAMP FEVER. Wyo. Agr. Exp. Sta. Ann. Rpt. 24: 159, 1913/14; 25: 104, 1914/15.

(13) ———
1915-18. THE TRANSMISSION OF SWAMP FEVER IN HORSES. Wyo. Agr. Exp. Sta. Ann. Rpt. 26: 88, 1915/16; 27: 153-154, 1916/17; 28: 84-85, 1917/18.

(14) ———
1915. INSECT TRANSMISSION OF SWAMP FEVER. Science 42: 659.

(15) ———
1917. SOME EXPERIMENTS ON THE TRANSMISSION OF SWAMP FEVER BY INSECTS. (Abstract) Anat. Rec. 11: 540-541.

(16) SCOTT, J. W.
1918. FURTHER EXPERIMENTS ON THE TRANSMISSION OF SWAMP FEVER. (Abstract) Anat. Rec. 14: 98-99.

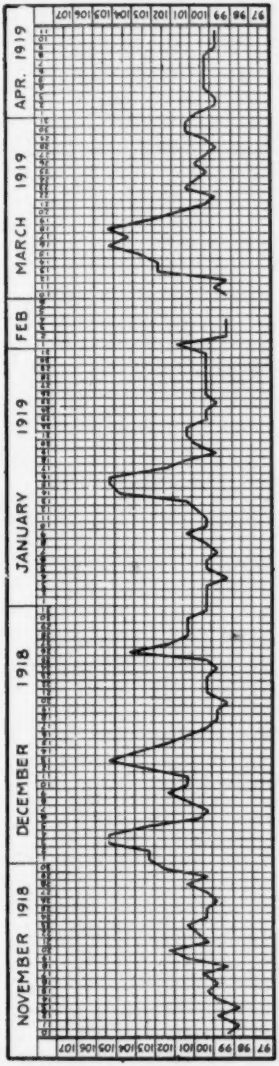

FIG. 12.—Temperature record of animal No. 2997

(17) ———
1920. EXPERIMENTAL TRANSMISSION OF SWAMP FEVER OR INFECTIOUS ANEMIA BY MEANS OF INSECTS. Jour. Amer. Vet. Med. Assoc. (n. s. 9) 56: 448-454.

(18) WRIGHT, L. H.
1920. A COMPARATIVE STUDY OF THE LONG BONES IN INFECTIOUS EQUINE ANEMIA AND OTHER CONDITIONS. Jour. Amer. Vet. Med. Assoc. (n. s. 9) 56: 444-447.